STOCHASTIC MODELLING AND FORECASTING OF SOLAR RADIATION

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ABSTRACT

From a review of the existing literature it was evident that statistical analysis and stochastic modelling of solar radiation has been applied to horizontal data recorded at sites remote from populated areas, in a deliberate attempt to eliminate the localised climatic effects of city centres. But both are very limited and unsophisticated. Various sampling intervals were adopted from 1 minute instantaneous values to hourly, daily and even monthly averages. In most other time series analysis applications the sampling frequency or sampling interval is set, for example annual crop yield, daily average temperature, monthly unemployment figures where a smaller sampling interval would be meaningless and impractical to impose. To model solar irradiance at smaller sampling intervals within an urban environment could stimulate investment in large-scale Photovoltaic Systems, which could be incorporated into the urban / national grid to provide predictable levels of base load. Since solar cells respond almost instantaneously to variations in solar irradiance, the instantaneous variations in power from a photovoltaic system have design implications for devices that transfer energy from the system to the grid. Being able to set a guaranteed low level of output from photovoltaic systems would be an important step forward in the integration of solar energy into the urban / national power grid. Therefore an understanding of high frequency variation may be necesary. This in turn requires a short sampling interval. For other applications, such as solar water heating, high frequency variation may not

be important. In such cases it is useful to know what the longest duration of sampling interval can be, or whether averaging the data over a sampling period would result in more predictable levels of base load. To this end the work reported in this thesis considered modelling solar irradiance in association with photovoltaic systems. Since solar cells respond almost instantaneously to variations in solar irradiance the major part of this work was to assess the optimal sampling interval at which to record data, horizontal and vertical both summer and winter. Knowing horizontal and vertical components the total on a plane normal to sun's rays can also be calculated (Chapter 2), also a possible application to panels that move so as to be normal at all times. The optimal sampling interval must reduce the amount of information lost but still contain the essential characteristics of the past behaviour of solar irradiance at that location.

This work involved statistical analysis of solar radiation values recorded at a measuring station situated on the city campus at the University of Northumbria, Newcastle-upon-Tyne, England. The first part of this work involved recording 10, 20, 30 and 60 minute averaged horizontal and vertical solar irradiance data over 13-15 day periods for three winters and summers. This data was then used to derive and compare ARIMA models for 10, 20, 30 and 60 minute averaged horizontal and vertical solar irradiance data. The second part considered 1, 5 and 10 minute instantaneous and 5 and 10 minute averaged horizontal and vertical solar irradiance data for one summer and one winter. This analysis modelled individual days separately with the days categorised as good, average or overcast depending on the percentage sunshine recorded on that day.

In both cases the ARIMA models were derived for original data and log transformed data and compared via their $\%R^2$ value. The models produced during this work were very good, giving $\%R^2$ values as high as 91% in some cases with the minimum of parameter estimates to be calculated.

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Nomenclature

Abbreviations

G_{sc} - the solar constant = 1353 W/m^2

G_o - extraterrestrial radiation on a horizontal surface

G - radiation on a horizontal surface at the earth's surface

H_o - daily total extra-terrestrial radiation on a horizontal surface

H - daily total radiation on a horizontal surface at the earth's surface

I_o - hourly total extra-terrestrial radiation on a horizontal surface

I - hourly total radiation on a horizontal surface

These letters are used with a combination of subscripts which are defined as

o - radiation above the earth's atmosphere

b - beam radiation

d - diffuse radiation

T - radiation on a tilted surface

n - radiation on a normal surface

if neither T nor n are present then the radiation is on a horizontal surface.

L_{st} = standard meridian for local standard time

L_{loc} = longitude of the location in question, in degrees West.

$\omega_s = \cos^{-1}(-\tan\phi \tan\delta)$ the sunset hour angle.

θ angle of incidence, which is the angle between the beam radiation on a surface and the normal to that surface

δ solar declination angle, zero at the vernal and autumnal equinoxes, +23.45 at the summer solstice and -23.45 at the winter solstice ($-23.45^0 \leq \delta \leq +23.45^0$)

ϕ latitude of the location($-90^0 \leq \chi \leq +90^0$)

β the tilt (or slope) angle between the plane surface in question and the horizontal ($0^0 \leq \beta \leq 180^0$)

γ surface azimuth angle, which is the deviation of the projection on a horizontal plane of the normal to the surface from the South, with zero due South, East negative and West positive ($-180^0 \leq \lambda \leq +180^0$)

ω hour angle, which is the angular displacement of the Sun East or West of the local meridian due to the rotation of the Earth around its axis $15^0\ h^{-1}$, with morning values negative and afternoon values positive.

Definitions

Several definitions are useful in understanding the effect of solar radiation on the earth's surface.

Irradiance, W/m^2 :

the rate at which radiant energy is incident on a surface per unit area of surface. The symbol G is used with appropriate subscripts for beam or diffuse radiation.

Irradiation or Radiant Exposure, J/m^2 :

the incident energy per unit area on a surface found by integration of irradiance over a specified time, usually an hour or a day. Insolation is a term applying specifically to solar energy irradiance. The symbol H is used for insolation for a day or other period if specified. The symbol I is used for insolation for an hour. H and I can be beam, diffuse or total and can be incident on surfaces of any orientation.

Zenith Angle, θ_z

the angle subtended by a vertical line to the zenith and the line of sight to the sun.

Air Mass, m :

the ratio of the optical thickness of the atmosphere through which beam radiation passes to the optical thickness if the sun were at its zenith, $m = (\cos\theta_z)^{-1}$.

Beam Radiation :

the solar radiation received from the sun without having been scattered by the atmosphere, often referred to as direct radiation.

Diffuse Radiation :

the radiation received from the sun after its direction has been changed by scattering by the earth's atmosphere.

Total Solar Radiation :

the sum of beam radiation and diffuse radiation on a surface, sometimes used to indicate quantities integrated over all wavelengths of the solar spectrum. The most common measurements of solar radiation are total radiation on a horizontal surface often referred to as global radiation.

1. Introduction

1.1. Background

Over the past twenty years research into photovoltaic technology has been making steady progress towards the development of a new and sustainable energy source, which will be of major importance to future generations. A photovoltaic (PV) module comprises a number of individual solar cells, connected together and encapsulated to protect them from weather or physical damage. The solar cells convert sunlight directly into electricity. This is a solid-state process, involving the excitation of electrons in the semiconductor material of which solar cells are made, followed by the collection of these electrons to form an electrical current. The process has no moving parts, is silent and has no by-products, with the only pollutants associated with PV systems resulting from their manufacture.

Photovoltaic systems are currently used throughout the world for specialist applications such as telecommunications in remote locations, rural lighting in developing countries, consumer goods, for which they are already economic. The grid-connected market for residential, commercial and industrial buildings is growing rapidly throughout the western world, in particular Europe, America and Japan. Solar radiation is monitored at several sites around the UK and is used for prediction of factors such as likely weather trends and solar gain in buildings.

The use of PV modules as a material for building cladding is a relatively new but rapidly growing technology in Europe. Improvements in PV efficiencies together with a reduction in production costs have led to widespread installation of PV modules on buildings in Switzerland, Germany and the Netherlands [1, 2, 3]. This method of installing PV technology has several advantages which can also make it attractive to the UK energy authorities and the building industry; firstly because the modules have a ready-made mounting structure, thus maximising on available space, and secondly the extra cost of cladding is offset against the saving made on electricity. The installation of PV technology in city-centres rather than in areas of unspoilt countryside may be seen as a further advantage.

The 1990 ETSU review [4] of PV technology in the UK indicated that the integration of PV modules into the building fabric of commercial buildings could be cost effective early in the next century. This led to an increase in Research and Development via participation in the International Energy Agency's PV on Buildings Programme [5]. As part of a DTI programme the Newcastle Photovoltaics Application Centre (NPAC) carried out a research project to estimate the potential total generating capacity of PV-clad buildings in the UK [6,7]. This project concluded that a significant proportion of solar energy available to the UK could be converted to electricity. This technology was identified by the former Department of Energy and by the UK's Technology Foresight Programme as having the potential to make a significant contribution to the UK energy supply and become a major energy technology in the next century. However, as outlined in [8], in order to determine the characteristics of an intermittent energy source, such as solar radiation, extensive monitoring of both solar irradiance and PV module response must first be carried out. As a result a solar monitoring station was established at the University of Northumbria, to record environmental conditions and PV module energy output for analysis.

1.2. Solar Radiation

The major factors influencing PV module output are solar irradiance, ambient temperature, type and efficiency of solar cell. The radiation outside of the earth's atmosphere, extraterrestrial radiation, varies due to the apparent motion of the sun, while irregular variations in terrestrial radiation, which occur inside the earth's atmosphere, are caused by climatic conditions, such as cloud cover, atmospheric water vapour content, dust content, ozone content and other radiation depleting factors. The properties of the solar irradiance are more important than ambient temperature since PV modules respond almost instantaneously to variations in solar irradiance.

The radiation emitted by the sun and its spatial relationship to the earth result in a nearly fixed intensity of solar irradiance outside of the earth's atmosphere. The solar constant, G_{sc}, is the energy from the sun per unit time received on a unit area of the surface perpendicular to the direction of propagation of the radiation at the earth's mean distance from the sun outside of the atmosphere. Direct measurements of solar irradiance outside most or all of the earth's atmosphere were made by very-high-altitude aircraft, balloons and spacecraft. These measurements were made with a variety of instruments in nine separate experimental programs detailed in [9 and 10] and resulted in a value of the solar constant, G_{sc}, of 1353 W/m^2.

However, there are two sources of variation in extraterrestrial radiation. The first is the variation in the radiation emitted by the sun. There are conflicting reports in the literature on periodic variations of solar radiation and it has been suggested that there are small variations, less than 1.5%, with different periodicities and variations, related to sunspot activities. The second is due to variations of sun-earth distance which leads to variation of extraterrestrial radiation flux in the range of 3%. The dependence of extraterrestrial radiation on time of year is given by

$$G_{on} = G_{sc}\left(1 + 0.033\cos\left(\frac{360n}{365}\right)\right),$$

Eq. 1.2.1

where G_{on} is the extraterrestrial radiation, measured on the plane normal to the radiation on the n^{th} day of the year, where n = 1 corresponds to 1^{st} January. The solar irradiance, G, can have a combination of two subscripts; the first subscript denotes whether the irradiance is extraterrestrial (o), beam (b) or diffuse (d); the second denotes whether the irradiance is on a tilted (t) or normal (n) surface. If neither t nor n are present then the radiation is on a horizontal surface. Absence of the first subscript denotes global terrestrial irradiance measured at the earth's surface.

The geometric relationships between a plane of any particular orientation relative to the earth at any time and the incoming beam solar irradiance can be described in terms of several angles. The angle of incidence, θ, of beam solar irradiance is given by the relationship :

$$\begin{aligned}\cos\vartheta = {} & \sin\delta\sin\phi\cos\beta \\ & - \sin\delta\cos\phi\sin\beta\cos\gamma \\ & + \cos\delta\cos\phi\cos\beta\cos\omega \\ & + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega \\ & + \cos\delta\sin\beta\sin\gamma\sin\omega,\end{aligned}$$

Eq. 1.2.2

where ϕ = latitude, δ = declination angle, β = the tilt (or slope) angle between the plane surface in question and the horizontal, γ = surface azimuth, ω = hour angle, which is the angular displacement of the Sun East or West of the local meridian. These angles are illustrated in Figure 1.2.1 (a). The geometrical relations between the beam radiation on a tilted surface, G_{bt}, and that on a horizontal surface, G_{bh}, with the beam radiation on a surface normal to the rays from the Sun are defined in Figure 1.2.1 (b) and (c).

For horizontal surfaces $\beta = 0^{\circ}$ and the incidence angle θ becomes the zenith angle of the Sun, θ_z, and Eq. 1.2.2 reduces to :

$$\cos\theta_z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega .$$

Eq. 1.2.3

For vertical surfaces $\beta = 90^{\circ}$ and Eq. 1.2.2 reduces to :

$$\cos\theta = -\cos\phi\cos\gamma\ \sin\delta + \sin\phi\cos\gamma\cos\delta\cos\omega + \cos\delta\sin\gamma\sin\omega$$

Eq. 1.2.4

At any point in time the solar irradiance outside the atmosphere incident on a horizontal plane, G_o, is defined by

$$G_o = G_{sc}\left[1 + 0.033\ \cos\left(\frac{360n}{365}\right)\right]\cos\theta_z .$$

Eq. 1.2.5

Combining with Eq. 1.2.3, G_o for a horizontal surface at any time between sunrise and sunset is given by

$$G_o = G_{sc}\left[1 + 0.033\ \cos\left(\frac{360n}{365}\right)\right] * \left(\sin\delta\sin\phi + \cos\phi\cos\delta\cos\omega\right).$$

Eq. 1.2.6

The daily total of extraterrestrial irradiation on a horizontal surface, H_o, is obtained by integrating Eq. 1.2.6 over the period from sunrise to sunset, hence

$$H_o = \frac{24 \cdot 3600 G_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right] * \left[\cos\phi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\phi\sin\delta\right],$$

Eq. 1.2.7

where ω_s is the sunset hour angle and H_o is in J/m^2.

The hourly total of extraterrestrial irradiation on a horizontal surface, I_o, is obtained by integrating Eq. 1.2.7 for a period defined by hour angles ω_1 and ω_2 (which define an hour, with $\omega_2 > \omega_1$). Hence

$$I_o = \frac{12*3600}{\pi} G_{sc}\left[1+0.033\left(\frac{360n}{365}\right)\right]$$
$$*\left[\cos\phi\cos\delta(\sin\omega_2 - \sin\omega_1) + \frac{2\pi(\omega_2 - \omega_1)}{360}\sin\phi\sin\delta\right].$$

Eq. 1.2.8

N.B. The limits ω_1 and ω_2 may define a time period other than one hour

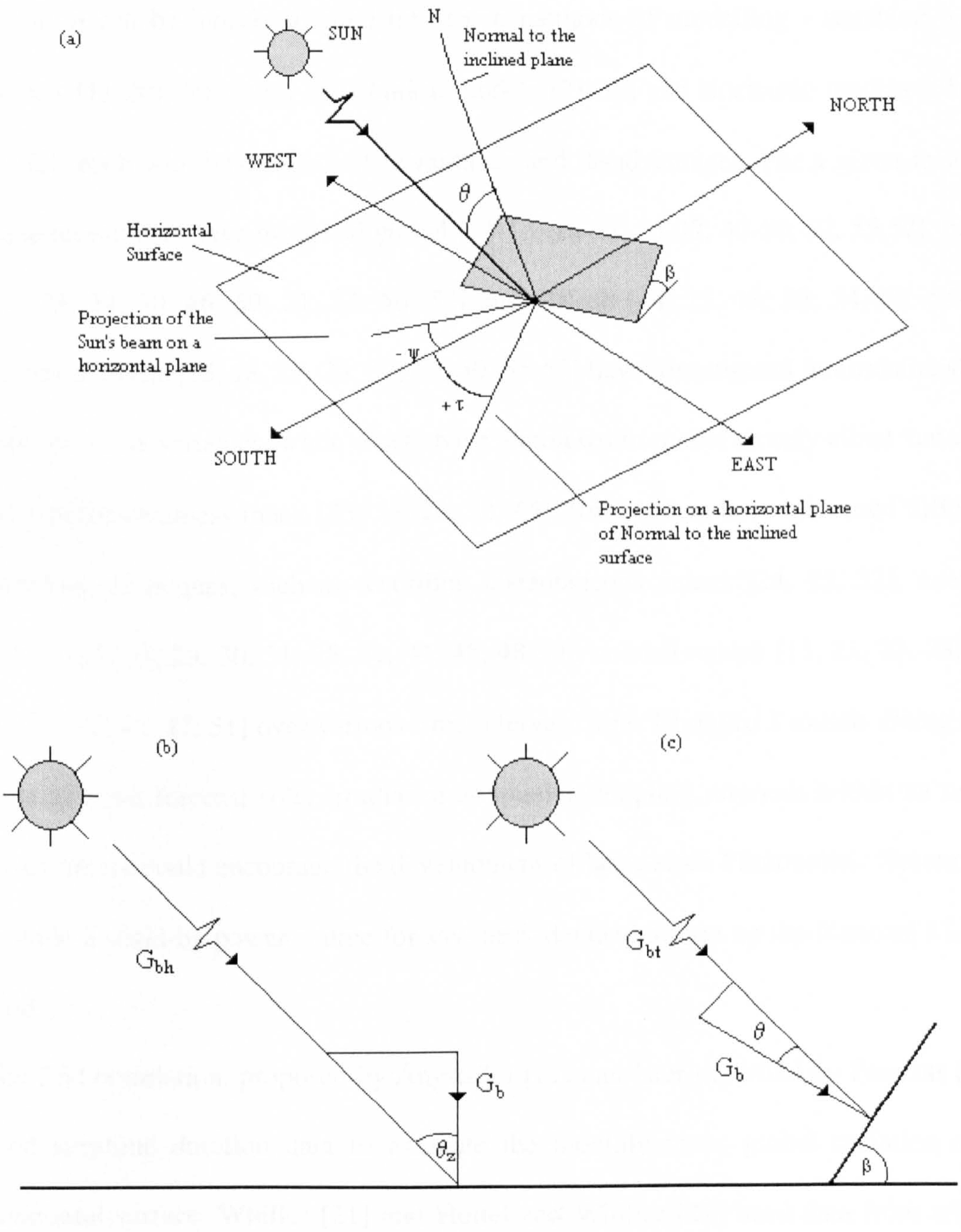
However, the extraterrestrial radiation at the top of the atmosphere is reduced as it passes through the earth's atmosphere due to the variability of the weather conditions. As a method of measuring this reduction Pereira and Rabl [25], Klein [61], Orgill and Hollands [54] defined the clearness index k_T, as the ratio of terrestrial hourly total radiation on a horizontal surface, I, to the extraterrestrial hourly total radiation on a horizontal surface, I_0. Therefore,

$$k_T = \frac{I}{I_0}.$$

Eq. 1.2.9

Other researchers [23, 26, 27] defined a clearness index as the ratio of terrestrial daily total radiation, H, to extraterrestrial daily total radiation, H_0, while Suehrcke and McCormick [32] defined a clearness index as the ratio of instantaneous terrestrial radiation, G, to instantaneous extraterrestrial radiation, G_0. In general, the clearness index is defined as the ratio of terrestrial to extrterrestrial radiation with appropriate subscripts for k, to indicate whether the ratio refers to global, beam (b) or diffuse (d) radiation, on a horizontal, normal (n) or tilted (t) surface.

Figure 1.2.1 (a) Position of the Sun relative to a tilted plane; (b) Irradiance on a horizontal surface; (c) Irradiance on a tilted surface.



1.3. Modelling of Solar Radiation

Modelling of solar radiation data is an essential step in the design and performance prediction of solar energy conversion systems. Previous attempts to model solar radiation can be loosely divided into three methods of modelling - sunshine based models [11-20], frequency distribution models [21-33] and stochastic models [35-37, 41-52], each with its own set of advantages and disadvantages. For a given location some researchers have modelled global [11-13, 16-33, 35-37, 40-50, 52, 55,57], beam [15, 23, 24, 30, 46, 50, 51, 53, 56, 57] and diffuse [14, 15, 18, 23, 24, 50, 54-58] radiation. Some [15, 18, 23- 25, 30, 46, 50, 55-57] have investigated interrelationships between these variables, while others have attempted to model closely allied variables such as the clearness index [23, 24, 27, 32, 44]. Researchers have also used different sampling techniques, such as recording instantaneous values [24, 25, 32], average values [15, 27, 29, 30, 31, 35, 41, 44, 45, 48-50], or total values [13, 21, 23, 28, 33, 36, 38, 42, 46, 47, 51] over various time intervals from 1 hour to 1 month. Being able to model and forecast solar irradiance at smaller sampling intervals within an urban environment could encourage the development of large-scale Photovoltaic Systems to provide a stand-by power source for say, peak demand, to top up the National / Local Grid.

The first correlation, proposed by Ångström [11] and later modified by Prescott [12], used sunshine duration data to estimate the monthly mean global radiation on a horizontal surface. Whiller [21] and Hottel and Whiller [22] used data from widely separated locations to obtain curves of hourly to daily radiation ratio against sunset hour angle.

Other researchers have also developed relationships between the ratios of global to diffuse radiation, global to direct and global to extraterrestrial radiation. Two of the most widely used correlations in this respect are given by Liu and Jordan [23] and Page [13]. Liu and Jordan first suggested a universal probability distribution for the clearness index, k, depending only on the monthly-average clearness index. Analytical formulae for the underlying probability density function were given by Bendt et al [26], Hollands and Huget [27] and Olseth and Skartveit [28]. Relationships for estimating the beam and diffuse component of monthly solar radiation have also been developed by Liu and Jordan [23], Page [13], as well as Erbs et al [57], Iqbal [15] and Collares-Pereira and Rabl [25]. The sequence of daily-global clearness index values has been studied by Graham et al [44] and Klein [60] while Liu and Jordan [23], Stanhill [14], Collares-Pereira and Rabl [25] and Erbs et al [57] developed empirical correlations to estimate the beam and diffuse components of daily radiation. Erbs et al [57] as well as Orgill and Hollands [54], Bruno [56], Boes et al [53], Bugler [55] and Spencer [58] developed empirical correlations to calculate the hourly diffuse radiation on a horizontal surface from hourly global radiation data.

Goh and Tan [36] highlighted two disadvantages of the existing graphical or mathematical models available, firstly, that forecasts made are essentially static with emphasis on steady-state processes and long term averages rather than short-term time dependent patterns of solar radiation and secondly that the precision of forecasts provided by the models can be made only with the assumption that the individual observations, from which the model is derived, change independently. However, actual weather conditions at a given location invariably change over periods of time, generating series of solar radiation observations which are not independent but correlated. The forecasts made by these graphical or mathematical models do not reflect short-term variations or make use of the correlated nature of solar radiation data and cannot be said to contain all the essential characteristics of the past behaviour of the solar radiation observed at that location. They concluded that solar radiation modelling could be improved through the use of stochastic models that account for short-term data variation and correlation.

Pioneering work in developing stochastic models for daily irradiation sequences was undertaken by Klein [34]. A central feature of his work was modelling the clearness index rather than the irradiation variable itself. On the other hand attempts have been made to model the irradiation sequence itself or closely allied variables. Brinkworth [35] applied the autoregressive-moving average (ARMA) stochastic method directly to daily irradiation sequences in the UK and found that the sequential characteristics could be well represented with a first-order autocorrelation model. Amato et al [41] found that daily global solar radiation sequences in Italy could also be described as a first-order autoregressive stochastic process independent of locality or season. Festa et al [48] modelled the transformed fluctuations of daily global horizontal solar radiation of Genoa (Italy), as an autoregressive process of order one, while Loutfi and Khitra [49] described the daily global horizontal solar radiation at Rabat (Morocco), by a linear autoregressive stochastic model of first or second order.

Paassen [38] modelled the Dutch irradiation sequence using a modified irradiation variable. Excell [39] and Vérgara-Dominquez et al [40] on the other hand studied the ratio of the irradiation to clear sky irradiation. Gordon and Reddy [45] recognised that previous research involving time series analysis of solar radiation data typically considered one location or, at best, a few locations of similar climatic conditions [35-

37, 39-42, 44, 59] and they analysed the daily global horizontal solar radiation statistics, checking for universal characteristics, of a large number of significantly different locations and climatic conditions.

The first step in time series analysis of solar radiation is to choose both the series size and the variable temporal scale. A majority of previous research was developed on a yearly [40, 41, 59], seasonal [35, 37] or monthly [41, 45, 49] basis. Previous analyses have concentrated on daily [35, 36, 41, 42, 44, 45, 47-49, 51] or hourly [36,43,46,52] time scale since standard monitoring of meteorological variables has traditionally generated daily or hourly averages. However, PV systems respond almost instantaneously to variations in solar input making hourly averages of solar radiation much less accurate in the determination of likely output.

Suehrcke and Mc Cormick [32] correlated 1 minute instantaneous global radiation with the average clearness index and air mass. Their results indicated that the fractional time distribution of daily insolation is not representative of instantaneous radiation. Morgan [50] obtained probability density functions of the beam, diffuse and global solar irradiances from measurements made at 10 second intervals and averaged over 10 minutes. However, the 10 minutes averaging time was chosen as a compromise based on the requirements of the research project for which the data were collected.

This diversity of research emphasises that no one model, variable, sampling frequency or sampling technique can be thought of as universal but depends on the region from which measurements are taken, the purpose of the research and the objectives of the researcher.

1.4. Aims and Objectives

As solar energy attempts to compete against other well-established forms of energy, the short-term variability of solar irradiance, particularly in locations with a changeable climate such as the UK, present a problem. Industry and Commerce must have a constant supply of energy to operate effectively, and for solar energy to compete, it must first be seen to be predictable. Forecasts made using time series models may form the basis of a decision-making process as to whether the energy-user could utilise the energy supplied by solar modules or whether to rely solely on the National Grid for a particular period (day/hour).

The two most important factors in PV module output is the amount of incident solar irradiance and the efficiency of the solar cells encapsulated within the PV module. The aim of this thesis is to consider the former and to investigate the characteristics of solar irradiance. As little information is available at urban sites, which would be particularly useful for solar panelling in cities, or at sites at northern latitudes, a city centre site in the UK was chosen. Aspects to be investigated are winter and summer, and horizontal and vertical solar irradiance levels. For the purposes of modelling and forecasting the incident solar irradiance night time data was discarded, because as revealed in initial investigation it contained no useful information.

Two major aims of the thesis are : to build time series models for solar irradiance and to investigate the optimal sampling interval for solar irradiance. Little work has been carried out into assessing the optimal sampling interval, which is particularly important in a location with a changeable climate.

Time series models which contain all the essential characteristics of past solar irradiance in order to forecast future solar irradiance will be fitted. This will require the use of more sophisticated time series modelling than presently available in the literature.

2. Monitoring Station and Data-sets

2.1. Monitoring Station

Newcastle upon Tyne is located in the north east of the UK mainland at latitude $54^{0}59'$ North, longitude $1^{0}37'$ West, 9 miles (approx. 14 km) from the coast and is subject to a cool temperate climate on the western margins. A solar radiation monitoring system was set-up on the roof of Pandon Building, part of the University of Northumbria's city campus situated near the city centre. The ground floor entrance is approximately 44.33 m above sea-level rising to the roof which is 13.80 m above the ground floor. This monitoring station, erected in April 1993, consists of four sets of photovoltaic modules mounted together with a weather monitoring station and data acquisition system on a scaffolding frame [see Photograph 1 and Photograph 2]. The frame was positioned to allow maximum exposure to the available insolation, oriented to face due south at solar noon and the experimental equipment was regularly maintained. Full details of this equipment are provided in Wilshaw [62].

2.1.1. Photovoltaic modules

Eight BP 460 monocrystalline silicon modules are mounted on the experimental rig : two modules placed vertically on the north facing side, two placed vertically on the south facing side and four on top. Of the four on the top, two are lying horizontal and two are tilted at an angle of 35° to the horizontal. The angle of tilt is readily adjustable to allow investigations of variations in annual output with the angle of solar incidence, θ. Each module is rated at 60W with a surface area of 0.442 m^2 and consists of 36 series connected cells.

Ten smaller M10 monocrystalline silicon modules are located in pairs to face north, south, east, west and south at 35° to the horizontal. Each module is rated at 10W with a surface area of 0.146 m^2 and consist of 36 quarter cells connected in series.

Two BP353ENM thin film cadmium telluride modules are mounted on the north and south faces of the scaffolding. These modules have a surface area of 0.143 m^2 with a power rating of 6W.

2.1.2. Weather Station

Two Kipp & Zonen CM11 pyranometers are mounted on the rig, (one on the horizontal plane on the top of the rig, the other on the south facing vertical plane), to measure global irradiance (kW/m^2). The device incorporates a thermopile, shielded by a hemispherical glass dome.

The Eppley Normal Incidence Pyrheliometer measures beam irradiance (kW/m^2) and employs a thermopile detector with a 5.7° field of view to exclude the detection of diffuse irradiance. The instrument is mounted on a solar tracker and aligned precisely in order to function. This requires frequent adjustment to the declination angle, δ, particularly around the equinox when the angle changes rapidly.

The A100R Anemometer, measuring wind speed in m/s, was manufactured by Vector Instruments and consists of three rotor cups which are mounted onto a spindle running in two precision ball-brace bearings. A magnet on the spindle opens and closes a mercury-wetted reed switch each time a revolution is completed. The instrument is constructed from anodised aluminium alloy with ABS plastic rotar cups and stainless steel shaft and bearings.

The wind vane, measuring wind direction, is a Vector W200P model, which incorporates a micro-torque wire-wound potentiometer with a filled gap to provide smooth operation and durability.

Ambient air temperature (degrees Celcius), is measured with a Fenwall Unicurve 2 k Ω hermetically sealed thermistor, mounted in an open cylindrical PTFE probe and shielded by a louvred, anodised aluminium radiation screen. The surface of the louvres is coated in a high reflectance, white, epoxy paint which prevents heating from direct radiation and keeps the housing close to ambient air temperature.

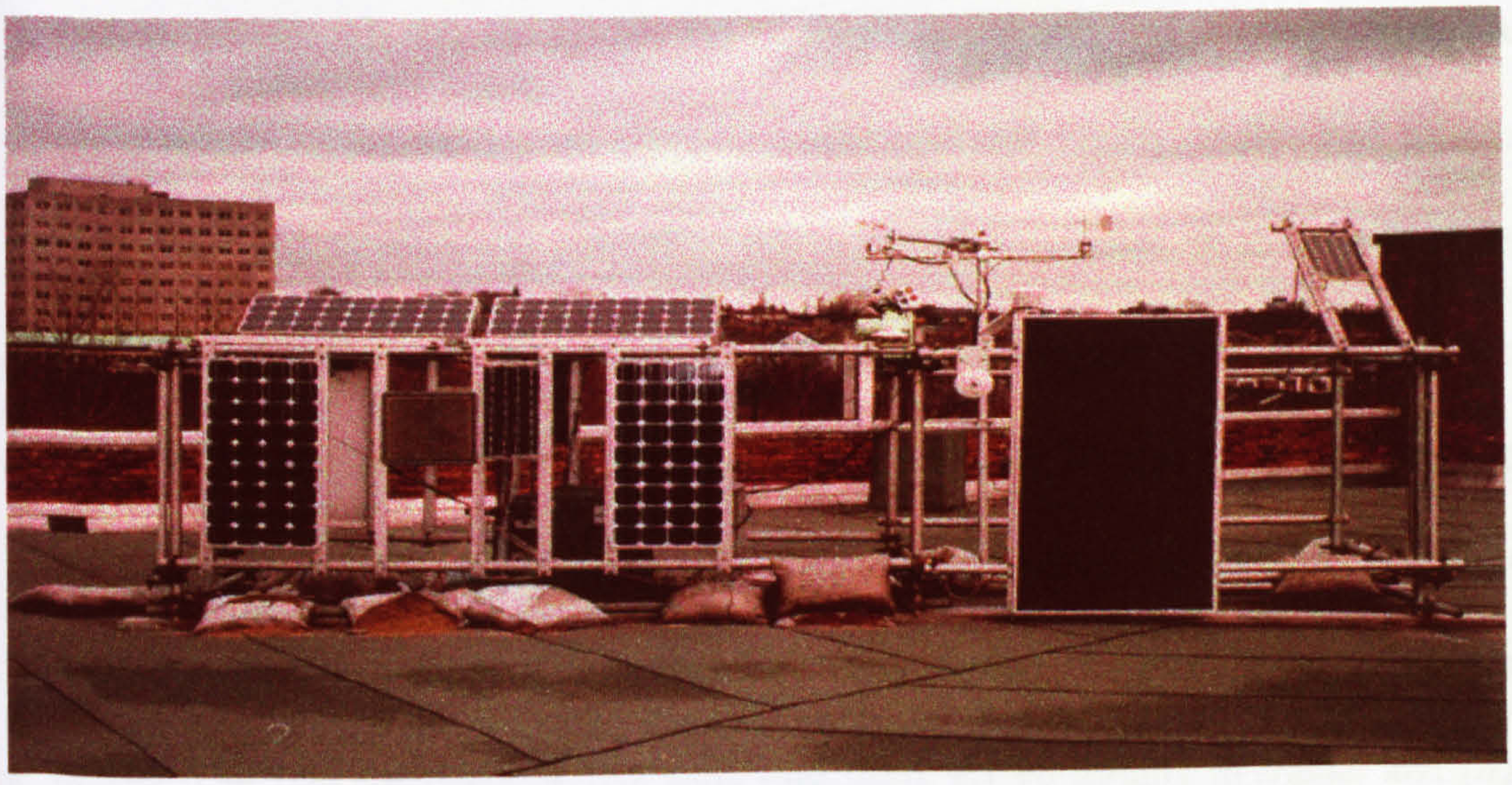
The relative humidity (RH%) sensor is mounted together with the ambient temperature sensor in the housing described above. The sensor head has a capacitance which alters in response to changes in humidity. It consists of a permeable, cracked chromium oxide top plate evaporated onto a dielectric, which is supported by a metal plate. The moisture is prevented from penetrating the dielectric by the narrow width (100 nm) of the cracks in the coating.

2.1.3. Data acquisition system

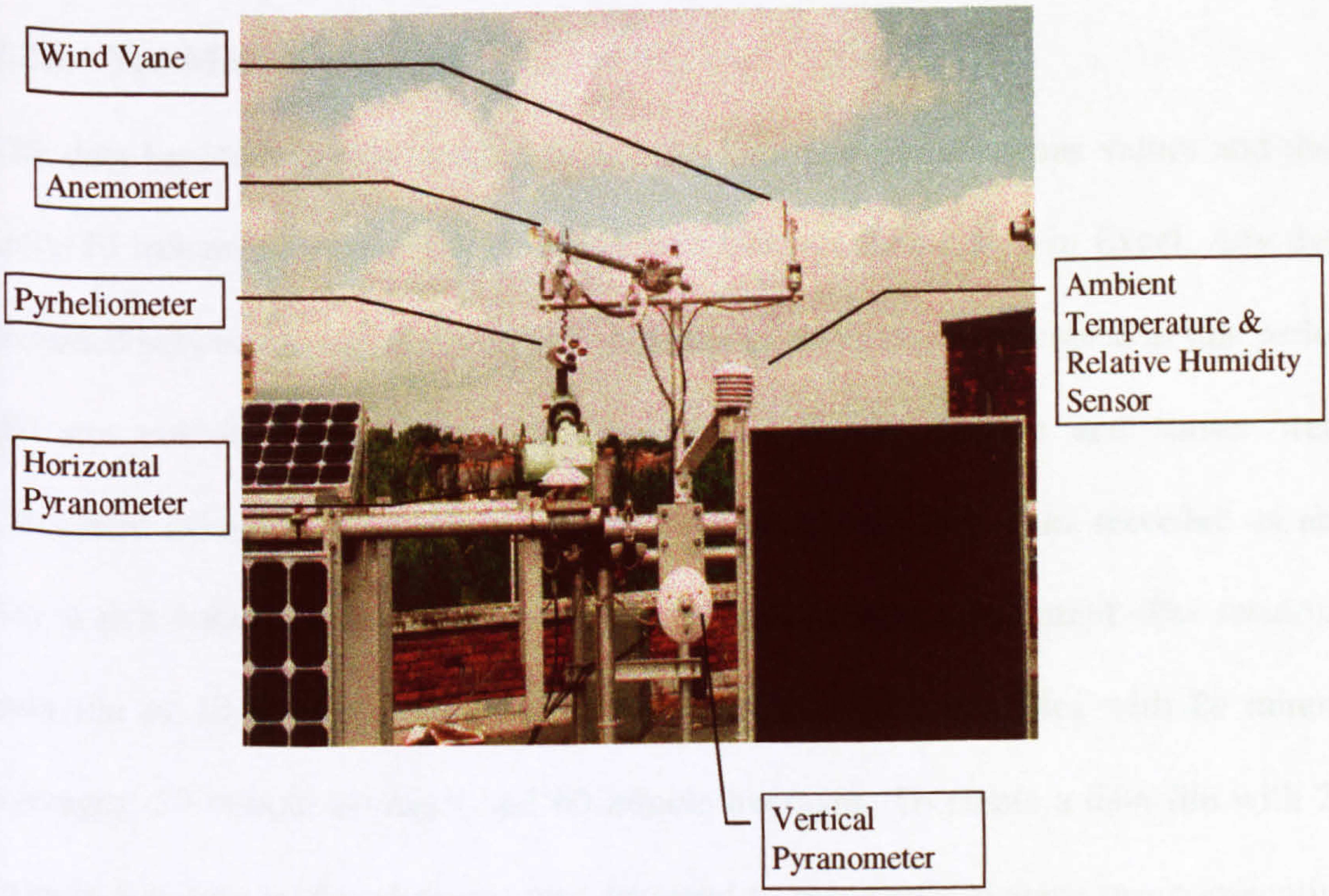
The data acquisition system is a programmable data-logger (supplied by Delta-T Devices Ltd.) which is capable of reading and storing signals from a wide range of sources. The sampling frequency can be varied from 1 second to 24 hour intervals and the readings manipulated before storage to memory. Averages, maxima, minima and instantaneous values can be selected and converted to engineering units before they are recorded. The logger has a 256 kB RAM, sufficient memory to store 128,000 readings. Data collection exceeding this limit overwrites the memory on a First-In-First-Out principle and a portable PC is used to transfer the data to disk before this occurs.

All the instruments and the PV modules are hardwired to the logger terminals after the necessary signal conditioning to convert and attenuate the outputs to the input range of the logger. The data are collected in binary format and subsequently converted to ASCII for spreadsheet analysis.

Photograph 1: Solar Cell arrays and weather monitoring instruments attached to the experimental rig on Pandon Building, University of Northumbria.



Photograph 2: Weather monitoring instruments attached to the experimental rig on Pandon Building, University of Northumbria.



2.2. Data-sets

Continuous data collection has been carried out since April 1993. Historically, solar irradiance and meteorological data has been analysed using hourly [36, 43, 46, 52], daily [35, 36, 41, 42, 44, 45, 47-49, 51] or monthly [41, 45, 49] averages. However, the UK is subject to short-term climatic variations and hourly, daily, and monthly averages are inappropriate for modelling this short-term variation. In this study shorter sampling frequencies are compared. Initially the data-logger was programmed to record 10 minute averages from which datafiles with 20, 30 and 60 minute averages were obtained. The data-logger was then programmed to record 1 minute instantaneous values from which datafiles with 5 and 10 minute averages were obtained. The two methods of data sampling used; (i) 10 minute averages and (ii) 1 minute instantaneous values, are described below with tables summarising the datafiles obtained.

2.2.1. Ten Minute averages

The data-logger was programmed to sample 1 minute instantaneous values and then store 10 minute averages. The resulting data file was then edited in Excel. Any data recorded between sunset and sunrise (i.e. hours of darkness) were erased as this period did not contain any information on solar irradiance. Sunrise and sunset were calculated using equations given in Duffie and Beckman [66]. Data recorded on any day which contained large blocks of missing values were also erased. The resulting data file of 10 minute averages was then used to create data files with 20 minute averages, 30 minute averages and 60 minute averages. To create a data file with 20 minute averages an Excel macro was designed to repeatedly average two consecutive 10 minute averages and store these averages in a new file. Similar macros were designed to create data files with 30 minute averages and 60 minute averages. The resulting data files were saved under file names which indicated the month, year and sampling frequency for that particular data file, for example DEC93_20 indicates that the file contains 20 minute averaged values recorded in December 1993. Table 2.2.1 provides details of the 10, 20, 30 and 60 minute data files, used in this study

2.2.2. One Minute Instantaneous

The data-logger was programmed to store 1 minute instantaneous values. Again, the original 1 minute data file was edited in Excel to remove (i) data between sunset and sunrise (ii) data recorded on any day which contained large blocks of missing values These 1 minute instantaneous data files were then used to create files with 5 minute averages and 10 minute averages. To create a data file of 5 minute averages, an Excel macro repeatedly averaged 5 consecutive 1 minute values and stored these in a new file. Similarly, to create a data file with 10 minute averages another Excel macro repeatedly averaged 10 consecutive 1 minute values and stored these in a new file. The resulting data files were saved under file names which indicated the month, year and sampling frequency for that particular data file. For example DEC93_01 indicates that the data in this file was recorded in December 1993 at 1 minute intervals. Data files containing 5 and 10 minute instantaneous values were also cretated from the 1 minute instantaneous data files by simply removing the intermediate values. Table 2.2.2 provides details of the 1 minute instantaneous, 5 minute instantaneous, 10 minute instantaneous, 5 minute averaged and 10 minute averaged data files used in this study.

Table 2.2.1 Summary of 10, 20, 30 and 60 minute averaged data files used in the analysis.

File name	no. obs.	start date	start time	end date	end time	no. obs/day
DEC93_10	600	17/12/93	08:46	31/12/93	15:26	40
DEC93_20	300	17/12/93	08:46	31/12/93	15:16	20
DEC93_30[1]	195	17/12/93	08:46	31/12/93	14:56	13
DEC93_60[2]	90	17/12/93	08:46	31/12/93	14:46	6
JUN94_10(1st-9th)	756	1/6/94	05:05	9/6/94	18:55	84
JUN94_20(1st-9th)	378	1/6/94	05:05	9/6/94	18:45	42
JUN94_30(1st-9th)	252	1/6/94	05:05	9/6/94	18:35	28
JUN94_60(1st-9th)	126	1/6/94	05:05	9/6/94	18:05	14
JUN94_10(18th-30th)	1092	18/6/94	05:05	30/6/94	18:55	84
JUN94_20(18th-30th)	546	18/6/94	05:05	30/6/94	18:45	42
JUN94_30(18th-30th)	364	18/6/94	05:05	30/6/94	18:35	28
JUN94_60(18th-30th)	182	18/6/94	05:05	30/6/94	18:05	14
DEC94_10(1st-15th)	540	1/12/94	09:00	15/12/94	14:50	36
DEC94_20(1st-15th)	270	1/12/94	09:00	15/12/94	14:40	18
DEC94_30(1st-15th)	180	1/12/94	09:00	15/12/94	14:30	12
DEC94_60(1st-15th)	90	1/12/94	09:00	15/12/94	14:00	6
DEC94_10(16th-31st)	576	16/12/94	09:00	31/12/94	14:50	36
DEC94_20(16th-31st)	288	16/12/94	09:00	31/12/94	14:40	18
DEC94_30(16th-31st)	194	16/12/94	09:00	31/12/94	14:30	12
DEC94_60(16th-31st)	96	16/12/94	09:00	31/12/94	14:00	6
JUN95_10	1092	1/6/95	05:08	13/6/95	18:58	84
JUN95_20	546	1/6/95	05:08	13/6/95	18:48	42
JUN95_30	364	1/6/95	05:08	13/6/95	18:38	28
JUN95_60	182	1/6/95	05:08	13/6/95	18:08	14

[1] The last 10-minute observation on each day, at 15:26, in the DEC93_10 data file was erased to leave a total of 585 10-minute observations. This new data file was then used to create a data file of 30 minute averages.

[2] The last observation in the DEC93_30 data file was erased to leave a total of 180 30-minute observations. This new data file was then used to create a data file of 60-minute averages.

Table 2.2.2 Summary of 1 minute instantaneous, 5 minute and 10 minute averaged data files used in the analysis.

File name	no. obs.	start date	start time	end date	end time	no. obs/day
JUL94_01	10890	9/7/94	03:45	19/7/94	20:14	990
JUL94_05	2178	9/7/94	03:45	19/7/94	20:10	198
JUL94_10	1089	9/7/94	03:45	19/7/94	20:05	99
instJUL94_05	2178	9/7/94	03:45	19/7/94	20:10	198
instJUL94_10	1089	9/7/94	03:45	19/7/94	20:05	99
DEC95_01	4680	7/12/95	09:00	19/12/95	14:59	360
DEC95_05	936	7/12/95	09:00	19/12/95	14:55	72
DEC95_10	468	7/12/95	09:00	19/12/95	14:50	36
instDEC95_05	936	7/12/95	09:00	19/12/95	14:55	72
instDEC95_10	468	7/12/95	09:00	19/12/95	14:50	36

3. Time Series Modelling

3.1. Introduction

Analysis of a time-series aims to develop a model which (a) contains all the essential characteristics of the past behaviour of the process being sampled, (b) makes the model understandable, (c) is easy to use for forecasting purposes and (d) is convenient to update as new information becomes available.

As a full account of the procedures for ARMA model identification, estimation, checking and forecasting are given in Box and Jenkins [68], only an outline of the methodology and analysis tools used in this study is presented here.

3.2. Time-series

A time-series is a set of observations generated sequentially in time. Assuming that observations are available at discrete, equi-spaced intervals of time then observations made at times t_1, t_2, ..., t_N, are denoted by $z(t_1)$, $z(t_2)$, ..., $z(t_N)$. When there are N successive values of such a time-series then $z_1, z_2, z_3, ..., z_N$ or $\{z_t\}$ $t = 1, 2, ... N$ where N is the total number of observations in the series, is used to denote observations made at equidistant time intervals t_0+h, t_0+2h, ..., t_0+Nh where t_0 is the origin and h is the unit of time, z_t is regarded as the observation at time t.

If future values of a time-series are exactly calculated by some mathematical function, the time-series is said to be deterministic. However, some processes cannot be described by an entirely deterministic model because of experimental errors of a random nature. For such a process it may be possible to derive a model based on the calculation of the probability that a future value lies between two specified limits. A model which describes the probability structure of a sequence of observations is called a stochastic process and a time-series of N successive observations, $z_1, z_2, z_3, \ldots, z_N$, is regarded as a sample realisation, from an infinite population of such samples, which could have been generated by the process.

A major objective of statistical investigation is to infer properties of the population from those of the sample. This requires methods of describing stochastic processes, time-series, and classes of stochastic models which occur in practical situations. There are two classes of stochastic processes, stationary and nonstationary.

3.3. Stationary Stochastic Processes

An important class of stochastic models for describing time series are the stationary models, which assume that the process remains in statistical equilibrium. A stochastic process is said to be strictly stationary if the joint probability distribution associated with m observations $z_{t_1}, z_{t_2}, z_{t_3}, \ldots, z_{t_m}$, made at any set of times $t_1, t_2, \ldots t_m$, is the same as that associated with m observations $z_{t_1+k}, z_{t_2+k}, z_{t_3+k}, \ldots, z_{t_m+k}$ made at times t_1+k, $t_2+k, \ldots, t_m+k$. When m = 1, the stationarity assumption implies that the probability distribution $p(z_t)$ is the same for all times t and may be written as p(z). Hence, the stochastic process has a constant mean,

$$\mu = E[z_t] = \int_{-\infty}^{\infty} zp(z)dz,$$

Eq. 3.3.1

which defines the level about which it fluctuates, and a constant variance

$$\sigma_z^2 = E\left[(z_t - \mu)^2\right] = \int_{-\infty}^{\infty} (z - \mu)^2 p(z)dz,$$

Eq. 3.3.2

which measures its spread about this level. Also, for a strictly stationary series all second order moments remain constant, i.e. independent of time t. Since the probability distribution p(z) is the same for times t, its shape can be inferred by forming the histogram of the observations $z_1, z_2, z_3, \ldots, z_N$ making up the observed time-series. In addition the mean μ of the stochastic process can be estimated by

$$\bar{z} = \frac{1}{N}\sum_{t=1}^{N} z_t \ ,$$

Eq. 3.3.3

and the variance of the stochastic process can be estimated by the variance of the time series

$$\hat{\sigma}_z^{\,2} = \frac{1}{N}\sum_{t=1}^{N}\left(z_t - \bar{z}\right)^2 .$$

Eq. 3.3.4

The stationarity assumption also implies that the joint distribution $p(z_t, z_{t+k})$ is the same for all times t, t+k, k = ± 1, ± 2, which are a constant interval apart.

A less restrictive requirement, used in practical situations, is weak stationarity, a time series is weakly stationary, or second-order stationary if

$$\begin{array}{llll} \text{(i)} & E[z_t] = \mu \quad \text{and} \quad \operatorname{var}[z_t] = \gamma_0 & \text{for all t} & t = 1,2,\ldots,N \\ \text{(ii)} & \operatorname{cov}(z_t, z_{t+k}) = \gamma_k & \text{for all t and k} & k = \pm 1, \ \pm 2,\ldots \end{array}$$

Eq. 3.3.5

where the covariance between z_t and z_{t+k}, separated by k intervals of time, is called the autocovariance at lag k and is defined by

$$\operatorname{cov}(z_t, z_{t+k}) = \gamma_k = E\left[(z_t - \mu)(z_{t+k} - \mu)\right].$$

Eq. 3.3.6

Condition (ii) implies that two observations, k time intervals apart, have the same covariance no matter where they occur in the time series. Conditions (i) and (ii) imply that we can define the autocorrelation between z_t and z_{t+k} as

$$\rho_k = \operatorname{corr}(z_t, z_{t+k}) = \frac{\operatorname{cov}(z_t, z_{t+k})}{\{\operatorname{var}(z_t)\operatorname{var}(z_{t+k})\}^{\frac{1}{2}}} \quad k = \pm 1, \ \pm 2, \ldots,$$

Eq. 3.3.7

$$\rho_k = \frac{E[(z_t - \mu)(z_{t+k} - \mu)]}{\sqrt{E[(z_t - \mu)^2][(z_{t+k} - \mu)^2]}} \quad .$$

Eq. 3.3.8

Since for a stationary process the variance $\sigma^2 = \gamma_0$ is the same at time t+k as at time t, this equation reduces to

$$\rho_k = \frac{E[(z_t - \mu)(z_{t+k} - \mu)]}{\sigma_z^2} \quad k = \pm 1, \ \pm 2, \ldots \ .$$

Eq. 3.3.9

Thus, the autocorrelation coefficient at lag k is

$$\rho_k = \frac{\gamma_k}{\gamma_0} \quad k = \pm 1, \ \pm 2, \ldots \quad ,$$

Eq. 3.3.10

which implies that $\rho_0 = 1$ and ρ_k is an even function where $\rho_k = \rho_{-k}$.

3.4. Time-Series Models

Stationary stochastic processes found to be very useful for modelling time-series are the autoregressive (AR), moving average (MA) and mixed autoregressive moving average (ARMA) processes. Their respective underlying models are described below, where the values of the process at equally spaced times are denoted by z_t, z_{t-1}, z_{t-2},... and $\tilde{z}_t, \tilde{z}_{t-1}, \tilde{z}_{t-2} \ldots$ are deviations from the mean μ; i.e. $\tilde{z}_t = z_t - \mu$.

Autoregressive (AR) Models

In this model the current value of the process is expressed as a finite linear aggregate of previous values of the process plus an error term, ε_t. The p^{th} order autoregressive model, AR(p), is given by

$$\tilde{z}_t = \phi_1 \tilde{z}_{t-1} + \phi_2 \tilde{z}_{t-2} + \ldots + \phi_p \tilde{z}_{t-p} + \varepsilon_t \qquad t = 1, 2, \ldots N,$$

Eq. 3.4.1

where $\phi_1, \phi_2, \ldots, \phi_p$ are constants and the error term ε_t is a 'white noise' process and is assumed to have the properties

$$\begin{array}{lll} E(\varepsilon_t) = 0, & \mathrm{var}(\varepsilon_t) = \sigma^2 & t = 1,\ 2,\ \ldots,\ N, \\ \mathrm{cov}(\varepsilon_t, \varepsilon_{t+k}) = 0, & k \neq 0 & k = \pm 1,\ \pm 2,\ \ldots \end{array} .$$

Eq. 3.4.2

The model contains p+2 unknown parameters, μ, ϕ_1, $\phi_2, \ldots, \phi_p$, σ_ε^2 which have to be estimated from the data. The parameter σ_ε^2 is the variance of the error terms ε_t defined in Eq. 3.4.2.

Moving Average (MA) Models

Another model of great importance in representing observed time series is the moving average process. In the q^{th} order moving average, MA(q), model

$$\tilde{z}_t = \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots - \theta_q \varepsilon_{t-q} \qquad t = 1, 2, \ldots N,$$

Eq. 3.4.3

where $\theta_1, \theta_2, \ldots, \theta_q$ are constants and ε_t is defined in Eq. 3.4.2. The model contains q+2 unknown parameters, μ, θ_1, $\theta_2, \ldots, \theta_q$, σ_ε^2 which have to be estimated from the data.

Mixed Autoregressive-Moving Average (ARMA) Models

To achieve greater flexibility in the fitting of actual time series it can be advantageous to include both autoregressive and moving average terms in the model. The autoregressive moving average model, with p autoregressive and q moving average parameters, ARMA(p,q), is given by

$$\tilde{z}_t = \phi_1 \tilde{z}_{t-1} + \ldots + \phi_p \tilde{z}_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \ldots - \theta_q \varepsilon_{t-q} \qquad t = 1, 2, \ldots, N,$$

Eq. 3.4.4

where μ, ϕ_1, ϕ_2, ... ϕ_p, θ_1, θ_2,... θ_q, σ_ε^2 are unknown constants which are estimated from the data, and ε_t is defined in Eq. 3.4.2.

3.5. Nonstationary Stochastic Processes

Many time series encountered exhibit nonstationary behaviour such as not varying about a fixed mean or possessing a trend. With suitable differencing this type of time series can often be reduced to a stationary series.

Differencing to remove a trend

To remove a linear trend the first difference of the a time series $\{z_t\}$ defined as

$$\nabla z_t = z_t - z_{t-1},$$

Eq. 3.5.1

is used; to remove a quadratic trend the second difference of the series defined as

$$\nabla^2 z_t = \nabla(\nabla z_t) = \nabla z_t - \nabla z_t,$$

Eq. 3.5.2

is used; to remove a d^{th} order polynomial the d^{th} difference defined as

$$\nabla^d z_t = \nabla^{d-1} z_t - \nabla^{d-1} z_{t-1} \qquad d = 1,2,..$$

Eq. 3.5.3

is used. Usually d is 0, 1 or 2 at the most, where $\nabla^o z_t \triangleq z_t$.

Integrated Autoregressive-Moving Average (ARIMA) Models

Time series which can be rendered stationary after appropriate differencing can often be represented by an autoregressive moving-average model, where the differenced series is fitted with an ARMA(p,q) model. This type of model is an Autoregressive Integrated Moving-Average, ARIMA(p,d,q), model where p and q are as before and d is the degree of differencing required to render the series stationary. This process provides a powerful model for describing stationary and nonstationary time series.

If $w_t = \nabla^d z_t$ is the appropriately differenced stationary series, this differenced series is fitted with a ARMA(p,q) model. The ARIMA(p,d,q) process is defined by

$$w_t = \phi_1 w_{t-1} + \ldots + \phi_p w_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \ldots - \theta_q \varepsilon_{t-q} \qquad t = 1, 2, \ldots, N,$$

Eq. 3.5.4

where $\phi_1, \phi_2, \ldots \phi_p, \theta_1, \theta_2, \ldots \theta_q, \sigma_\varepsilon^2$ are unknown constants which are estimated from the data, and ε_t is defined in Eq. 3.4.2.

Differencing to remove a cyclic effect

Some time series may exhibit periodic behaviour of length s, where similarities in the series occur after s basic time intervals, where s = 2, 3,.... Generally a seasonal ARMA(P,Q) model may be defined as

$$y_t - \Phi_1 y_{t-s} - \ldots - \Phi_P y_{t-P_s} = \varepsilon_t - \Theta_1 \varepsilon_{t-s} - \ldots - \Theta_Q \varepsilon_{t-Q_s} \qquad t = 1, 2, \ldots, N,$$

Eq. 3.5.5

where capital letters are reserved for seasonal parameters. The autocorrelation function, defined in the next section, of a time series with seasonal components tends to have extrema at lags 1s, 2s, 3s and so on.

With the exception of occasional items, few series are purely seasonal and most contain a trend and a seasonal component. Whereas regular differencing is used to remove a trend from a nonseasonal series, seasonal differencing accomplishes an element of both deseasonalisation and trend removal. The first seasonal difference at period s is defined as

$$\nabla_s z_t = z_t - z_{t-s}$$

$$t = 1, 2, \ldots, N.$$
$$s = 2, 3, \ldots\ldots$$

Eq. 3.5.6

The notation ARIMA(p,d,q)(P,D,Q)s is used to refer to a mixed seasonal model of period s with regular and seasonal components of order p and P for AR, q and Q for MA and d and D for differencing.

3.6. Model Identification : Tools and Methodology

Two tools used to identify the orders *p* and *q* for the autoregressive and moving average operators are the Autocorrelation Function (ACF) and the Partial Autocorrelation Function (PACF).

The Autocorrelation Function is defined as the plot of the autocorrelation coefficient[3], ρ_k, as a function of the lag k. The partial autocorrelation coefficient, ϕ_{kk}, is the autocorrelation between two values, z_t and z_{t+k}, after allowing for the effect of the intervening values, z_{t+1}, z_{t+2},...z_{t+k-1}. The Partial Autocorrelation Function (PACF) is defined as the plot of the partial autocorrelation coefficient, ϕ_{kk}, against the lag k.

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[3] The autocorrelation coefficient is defined in Section 3.3.

In the practical situation the autocorrelation and partial autocorrelation coefficients are unknown and have to be estimated from the time-series.

The Autocorrelation Coefficient Estimates

In practice there are a finite number of observations, $z_1, z_2, \ldots, z_N$ of a process from which estimates of the autocorrelation coefficients are calculated and plotted against lag k to form the autocorrelation function (ACF). A number of techniques for estimating the autocorrelation coefficients have been suggested by statisticians and their properties are discussed in particular in Jenkins and Watts [69]. It is concluded that the most satisfactory estimate of the k^{th} lag autocorrelation, r_k, is

$$r_k = \frac{c_k}{c_0},$$

Eq. 3.6.1

where

$$c_k = \frac{1}{N}\sum_{t=1}^{N-k}(z_t - \bar{z})(z_{t+k} - \bar{z}), \qquad k = 0,1,2,3\ldots..N,$$

Eq. 3.6.2

and $\bar{z}$ is the mean of the time series. To obtain a useful estimate of the ACF at least 50 observations are needed and the estimated autocorrelations, r_k, are calculated for k = 0,1,..., K, where K was not larger than N/4.

Standard Error of Autocorrelation Estimates

To identify time series models it is necessary to have a check on whether r_k is effectively zero beyond a specified lag. For this purpose use can be made of the following approximate expression for the variance of the estimated autocorrelation coefficient of a stationary Normal process given by Bartlett [63] is:

$$\mathrm{var}[r_k] \simeq \frac{1}{N}\sum_{v=-\infty}^{+\infty}\{\rho_v^2 + \rho_{v+k}\rho_{v-k} - 4\rho_k\rho_v\rho_{v-k} + 2\rho_v^2\rho_k^2\}.$$

Eq. 3.6.3

Thus for the variance of the estimated autocorrelations, r_k, at lags greater than some value q beyond which the theoretical autocorrelation function may be deemed to have died out, Bartlett's approximation gives

$$\mathrm{var}[r_k] \simeq \frac{1}{N}\left\{1+2\sum_{v=1}^{q}\rho_v^2\right\} \qquad k>q.$$

Eq. 3.6.4

On the assumption that the series is completely random, q = 0 and then for all lags

$$\mathrm{var}[r_k] \simeq \frac{1}{N}.$$

Eq. 3.6.5

These results may be used to obtain a significance test based on the normal critical values.

The Partial Autocorrelation Estimates

An estimate of the partial autocorrelation coefficient, ϕ_{kk}, defined in Box & Jenkins [68] as

$$\hat{\phi}_{kk} = r_1 \qquad k=1$$

$$= \frac{r_1 - \sum_{j=1}^{k-1} \hat{\phi}_{k-1,j} r_{k-j}}{1-\sum_{j=1}^{k-1} \hat{\phi}_{k-1,j} r_j} \qquad k=2,3,\ldots,K$$

Eq. 3.6.6

where

$$\hat{\phi}_{klj} = \hat{\phi}_{k-1,j} - \hat{\phi}_{kk}\hat{\phi}_{k-1,k-j} \qquad j=1,2,\ldots,k-1.$$

Eq. 3.6.7

The Partial Autocorrelation Function, (PACF), is useful in model identification. As an AR(p) process has an autocorrelation function which is infinite in extent, it can by its nature be described in terms of p non-zero functions of the autocorrelations. For an autoregressive process of order p, the partial autocorrelation coefficients will be nonzero for k less than or equal to p and zero for k greater than p, i.e. the partial autocorrelation function of a p^{th} order autoregressive process has a cut-off after lag p.

Standard Errors of Partial Autocorrelation Estimates

It was shown by Quenouille [64] that on the hypothesis that the process is autoregressive of order p, the estimated partial autocorrelations of order p+1, and higher, are approximately independently distributed. Also if N is the number of observations used in fitting,

$$\mathrm{var}\left[\hat{\phi}_{kk}\right] \simeq \frac{1}{N}, \qquad k \geq p+1.$$

Eq. 3.6.8

Thus the standard error (S.E.) of the estimated partial autocorrelation $\hat{\phi}_{kk}$ is

$$\mathrm{S.E.}\left[\hat{\phi}_{kk}\right] \simeq \frac{1}{\sqrt{N}}, \qquad k \geq p+1.$$

Eq. 3.6.9

In this thesis the estimated partial autocorrelation coefficient, $\hat{\phi}_{kk}$, is significant at the 5% level (i.e. nonzero) if

$$\hat{\phi}_{kk} \neq 0 \text{ if } \left|\hat{\phi}\right| > \frac{1.96}{\sqrt{N}}.$$

Eq. 3.6.10

3.7. Identification Methodology

The expected behaviour of the ACF and PACF for different ARMA schemes is summarised in Table 3.7.1, and a complete description can be obtained in Box and Jenkins [68]. The ACF of an autoregressive process of order p tails off while its PACF has a cut-off after lag p. Conversely, the ACF of a moving average process of order q has a cut-off after lag q while its PACF tails off. If both ACF and PACF tail off, a mixed autoregressive moving average process is suggested. Comparing the estimates of the ACF and PACF with the expected behaviour forms the basis of selecting an initial tentative model to be fitted to the time series.

Table 3.7.1 Behaviour of Theoretical ACF and PACF for selected ARMA schemes.

Model	ACF	PACF
AR(p)	Tails off	Cuts off after lag p
MA(q)	Cuts off after lag q	Tails off
ARMA(p,q)	Tails off	Tails off

Identifying the degree of differencing

If the time series is nonstationary with a strong trend, the estimated ACF will die down extremely slowly. When this type of behaviour is exhibited, the usual approach is to compute the ACF and PACF of the first differenced time series. If the ACF and PACF behave according to the theoretical patterns of Table 3.7.1 then one difference is necessary to produce stationarity, if not then successively higher orders of differencing are attempted to obtain a stationary time series.

If the time series is nonstationary with a cyclical effect, the estimated ACF will have significant values coinciding with the length of the cycle, k. The usual approach here is to compute the ACF and PACF of the first differenced time series at the cycle length, s, and compare with the theoretical patterns in Table 3.7.1.

3.8. Model Fitting and Validation

The MINITAB and SPSS statistical packages were used to fit the ARIMA models for this study. After a tentative model has been fitted to the data, it must be validated and if necessary improvements made. The output obtained from the statistical packages consists parameter estimates, standard deviations of these estimates, t-ratios, sum of squares of the errors and the mean sum of squares of the errors. The t-ratios determined whether any parameters should be dropped from the proposed model. The parameters should also be checked for stationarity (after differencing) and invertability. The conditions for stationarity are that the roots of the equation

$$\phi(x) = 0,$$

Eq. 3.8.1

should be greater than 1 in absolute value; similarly, the conditions for invertability are that the roots of

$$\theta(x) = 0,$$

Eq. 3.8.2

should be greater than 1 in absolute value.

The mean sum of squares of the errors, MS, was used to obtain a measurement of the total amount of variance in the data that was accounted for by the fitted model. This is expressed as the adjusted R^2 % defined as

$$R^2\% = \left(1 - \frac{MS}{(\sigma^{\cdot})^2}\right) * 100,$$

Eq. 3.8.3

where $\sigma^{\cdot}$ is the standard deviation of the original time series.

3.9. Model Validation

Two types of check were performed before any model was considered adequate for the data, residual analysis and overfitting.

A plot of the residuals can be useful in identifying any unusual values, or increasing (decreasing) dispersion which may suggest the need to transform the data. Examining the ACF of the residuals helps to determine whether additional parameters are required. If the model is adequate then the residuals should conform to a white noise process and the ACF of the residuals should have no structure. If any of these autocorrelation coefficients are significantly different from zero, a different model is fitted with the apparent structure incorporated into it.

Overfitting is a process of fitting two further models to the time series. If the most appropriate model is an ARIMA(p,d,q) then a model with an extra AR parameter i.e. ARIMA(p+1,d,q), and a model with an extra MA parameter i.e. ARIMA(p,d,q+1), is fitted to see if the model fit, R^2 % , can be improved. If not, then the model with the fewest parameters to estimate with the highest R^2 % is selected as the best model for the time series.

3.10. Variance Stability

The condition of stationarity is fundamental to the statistical analysis of time series, and needs to be investigated. In practice for any particular time series, the conditions in Eq.3.3.5 must be satisfied, at least to a reasonable degree. Assuming that the series has been, or can be, rendered stationary in the mean, the next question which arises is that of variance stability i.e. are the mean and variance related. If this is found to be the case, then it must be corrected. Klein [34] recognised that when the ARMA process was applied to a standardised series of clearness indices, it was impossible to satisfy necessary Gaussian requirements. Klein's approach was to investigate transforming the series to a new set for which a Gaussian representation would be plausible. Box and Jenkins [68] also recognised that many physical systems are non-

Gaussian and direct application of ARMA modelling techniques to these processes would yield models with output variables represented by Gaussian distributions that are very different from the distribution of the historical sequence. Various general techniques have been investigated for transforming time series, the most popular method is a family of power transformations, due to Box and Cox [65].

Box and Cox [65] introduced the class of variance stabilising transformations

$$\begin{aligned} y^{(\lambda)} &= \frac{y^{\lambda}-1}{\lambda} & \lambda \neq 0 \\ &= \log_e y & \lambda = 0 \end{aligned},$$

Eq. 3.10.1

where typically $-1 \leq \lambda \leq 1$ and the random variable y is such that the probability of a negative value is negligible. Provided $\mu^2 * \gamma_0$, an approximation for the variance of the transformed variable is

$$\operatorname{var} y^{(\lambda)} \doteq \mu^{2\lambda-2}\operatorname{var}(y).$$

Eq. 3.10.2

Thus if the variance of y appears to increase linearly with the mean, we should use $\lambda = 0.5$. If the variance increases quadratically with the mean, $\lambda = 0$ i.e. the log transformation is appropriate.

Box and Cox [65], estimated λ by maximum likelihood, here a combination of two methods is used for the values $\lambda = -1, -0.5, 0, 0.5, 1$

(i) the comparison of correlation coefficients between the mean and variance

(ii) graphical checks, suggested by Kendall and Ord [67]

Two data-sets of 1 minute instantaneous values, JUL94_01[4] and DEC95_01[5], were analysed to ascertain whether a transformation of solar irradiance data was required and, if needed, the type of transformation.

The data-sets were split into individual days and each day analysed separately. The original 1 minute instantaneous data values were transformed using Eq. 3.10.1, with λ = -1, -0.5, 0 and 0.5. An Excel macro was designed to repeatedly calculate and store the mean and variance of 10 consecutive 1 minute instantaneous data values, for each day.

For each value of lambda, the correlation coefficient, ρ, between the mean and variance, for each day is used as a measure of this relationship. A correlation coefficient which is not significant indicates that there is no relationship between the mean and variance, and so that value of lambda is the most appropriate value to be used in transforming the data.

The significance of the correlation coefficients was tested using a 2-sided test (equal sample sizes), with $H_0 : \rho = 0$ against $H_1 : \rho \neq 0$. The critical regions are defined as

	July 1994 (n = 99)	December 1995 (n = 36)
5% critical region	0.1986	0.3291
1% critical region	0.2591	0.4238

The correlation coefficients between the mean and variance of 10 consecutive 1 minute observations for each day and lambda for the Horizontal and Vertical solar irradiance data recorded in July 1994, are displayed in Table 3.10.2 and Table 3.10.3, respectively. The correlation coefficients between the mean and variance of 10

[4] This data-set is fully described in Section 2.2.2.

[5] This data-set is fully described in section 2.2.2.

consecutive 1 minute observations for each day and lambda for the Horizontal and Vertical solar irradiance data recorded in December 1995, are displayed in Table 3.10.4 and Table 3.10.5, respectively. From Table 3.10.2 and Table 3.10.3 some of the correlation coefficients between the mean and the variance, with $\lambda = 0$, are significant. However, all the coefficients relating to $\lambda = 0$ are smallest in modulus. From Table 3.10.4 and Table 3.10.5 the majority of correlation coefficients relating to $\lambda = 0$ are not significant but not all are smallest in modulus.

Two typical days, one from each data-set, were selected to graphically show the effect of transforming the solar irradiance data. Figure 3.10.1 and Figure 3.10.2 displays the Original & Log Transformed Horizontal and the Original & Log Transformed Vertical Solar Irradiance recorded on 14th July 1994, respectively. Figure 3.10.3 and Figure 3.10.4 displays the Original & Log Transformed Horizontal and the Original & Log Transformed Vertical Solar Irradiance recorded on 12th December 1995, respectively. From the correlation coefficients and the graphs it was concluded that the most appropriate value of lambda to stabilise the variance was $\lambda = 0$ (i.e. a log transformation).

Table 3.10.2 Daily Correlation Coefficients between the mean and variance, for different lambda, of 1 minute Horizontal Solar Irradiance data recorded in July 1994

	λ				
Date	1	0.5	0	-0.5	-1
9/7/94	0.499	0.385	0.154	0.544	0.699
10/7/94	0.722	0.567	0.043	0.721	0.884
11/7/94	0.705	0.628	0.360	0.629	0.740
12/7/94	0.507	0.401	-0.097	0.733	0.711
13/7/94	0.636	0.529	0.315	0.712	0.903
14/7/94	0.287	0.282	0.197	0.697	0.834
15/7/94	0.475	0.444	0.252	0.586	0.657
16/7/94	0.580	0.441	0.180	0.706	0.854
17/7/94	0.481	0.389	0.107	0.731	0.841
18/7/94	0.536	0.444	0.066	0.806	0.890
19/7/94	0.453	0.393	0.183	0.776	0.875

Table 3.10.3 Daily Correlation Coefficients between the mean and variance, for different lambda, of 1 minute Vertical Solar Irradiance data recorded in July 1994

	λ				
Date	1	0.5	0	-0.5	-1
9/7/94	0.582	0.438	0.207	0.531	0.638
10/7/94	0.496	0.366	-0.041	0.733	0.825
11/7/94	0.714	0.640	0.383	0.719	0.856
12/7/94	0.573	0.500	0.005	0.690	0.732
13/7/94	0.727	0.656	0.477	0.661	0.892
14/7/94	0.308	0.298	0.229	0.694	0.823
15/7/94	0.454	0.427	0.305	0.671	0.804
16/7/94	0.636	0.571	0.411	0.716	0.851
17/7/94	0.629	0.568	0.396	0.708	0.911
18/7/94	0.680	0.582	0.221	0.706	0.868
19/7/94	0.486	0.455	0.324	0.703	0.861

Figure 3.10.1 Horizontal Solar Irradiance data, 14th July 1994

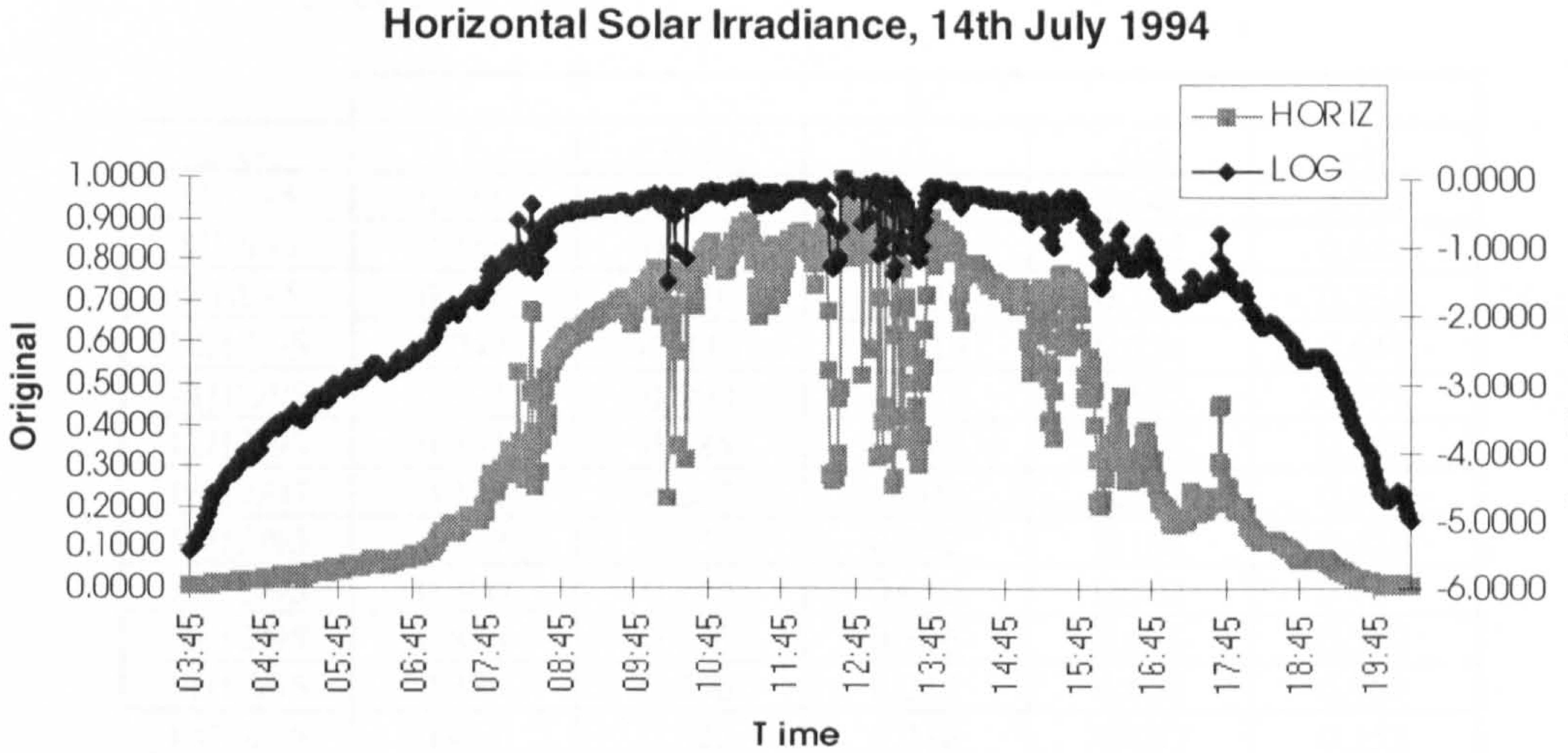


Figure 3.10.2 Vertical Solar Irradiance data, 14th July 1994

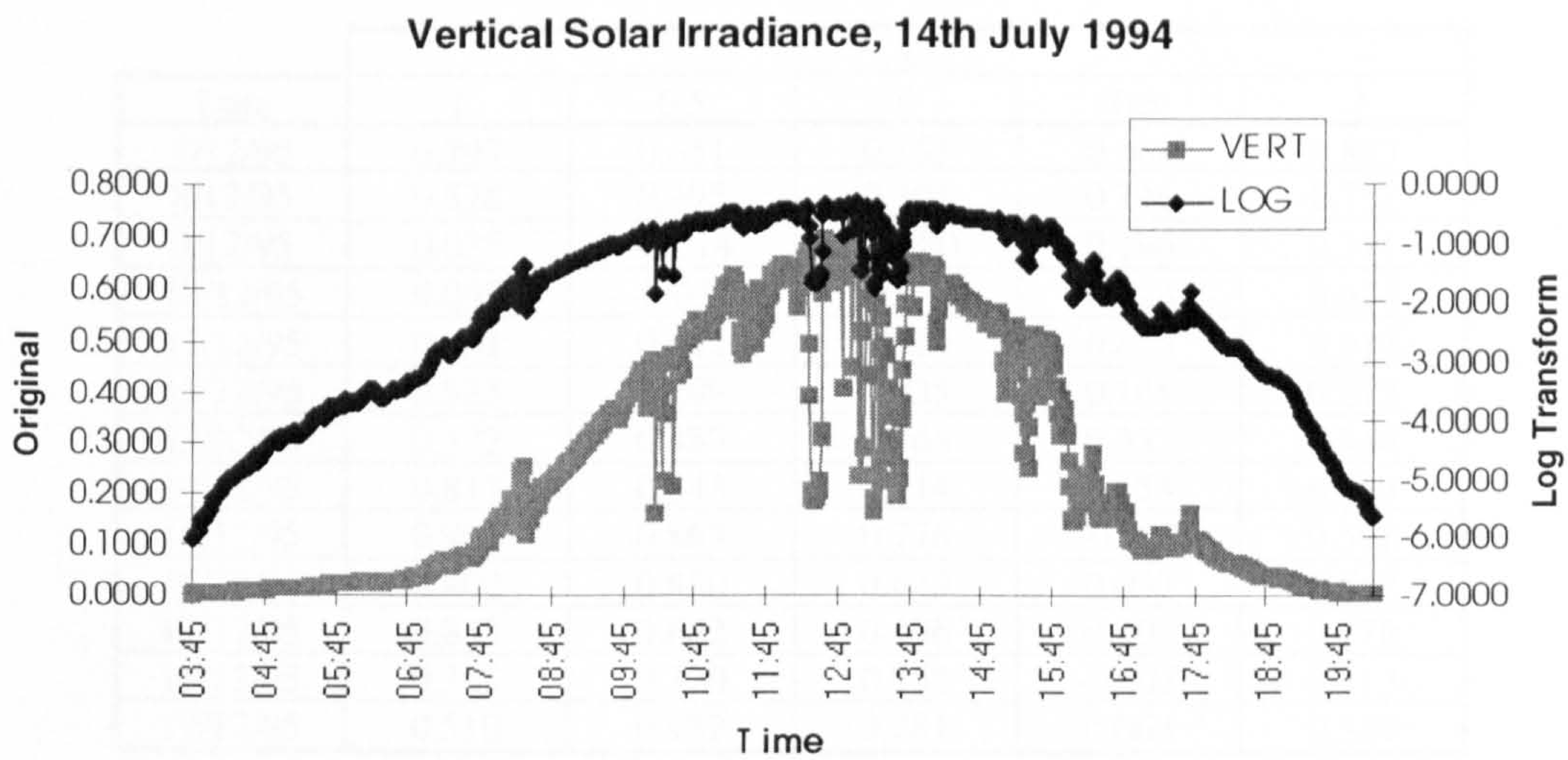


Table 3.10.4 Daily Correlation Coefficients between the mean and variance, for different lambda, of 1 minute Horizontal Solar Irradiance data recorded in December 1995

	λ				
Date	1	0.5	0	-0.5	-1
7/12/95	0.666	0.467	-0.280	0.647	0.784
8/12/95	0.484	0.430	0.164	0.532	0.685
9/12/95	0.104	0.029	-0.058	0.176	0.333
10/12/95	0.047	-0.113	-0.319	0.534	0.649
11/12/95	0.391	0.290	-0.116	0.607	0.798
12/12/95	0.491	0.285	-0.004	0.215	0.315
13/12/95	0.394	0.265	-0.047	0.501	0.698
14/12/95	0.727	0.651	0.342	0.165	0.439
15/12/95	0.800	0.743	0.610	0.103	0.787
16/12/95	0.839	0.755	0.526	0.146	0.560
17/12/95	0.489	0.430	0.212	0.660	0.909
18/12/95	0.411	0.322	0.216	-0.077	0.152
19/12/95	0.352	0.199	0.069	0.076	0.270

Table 3.10.5 Daily Correlation Coefficients between the mean and variance, for different lambda, of 1 minute Vertical Solar Irradiance data recorded in December 1995

	λ				
Date	1	0.5	0	-0.5	-1
7/12/95	0.797	0.651	0.151	0.668	0.843
8/12/95	0.528	0.495	0.401	0.146	0.752
9/12/95	0.035	-0.014	-0.080	0.196	0.311
10/12/95	0.099	-0.037	-0.090	0.224	0.654
11/12/95	0.531	0.442	0.089	0.445	0.613
12/12/95	0.525	0.299	0.025	0.168	0.273
13/12/95	0.572	0.489	0.268	0.351	0.744
14/12/95	0.817	0.843	0.714	0.158	0.633
15/12/95	0.905	0.863	0.776	-0.307	0.598
16/12/95	0.902	0.850	0.648	0.037	0.547
17/12/95	0.835	0.682	0.496	0.202	0.776
18/12/95	0.365	0.320	0.258	-0.078	0.513
19/12/95	0.510	0.432	0.281	0.063	0.389

Figure 3.10.3 Horizontal Solar Irradiance data, 12th December 1995.

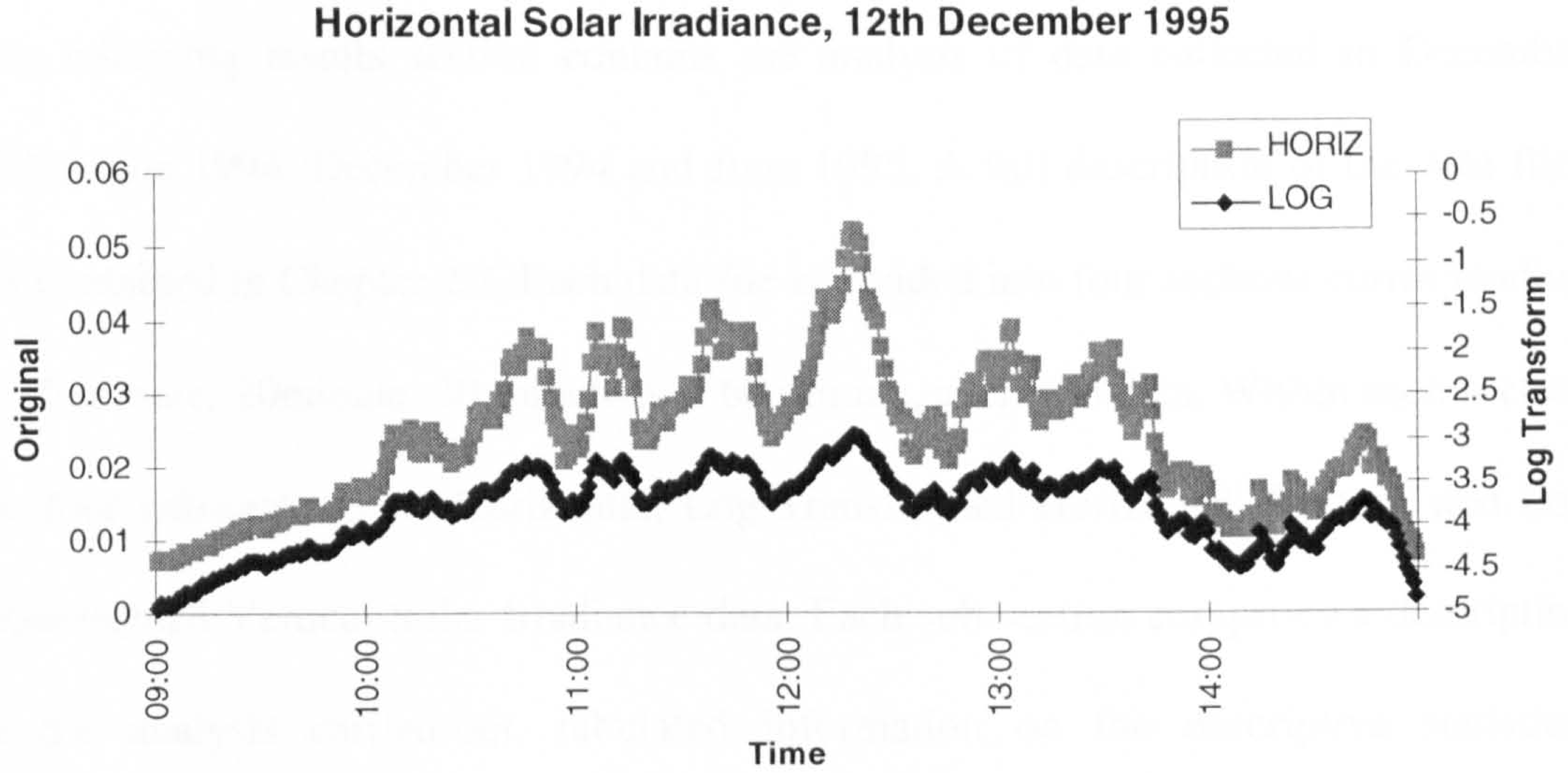
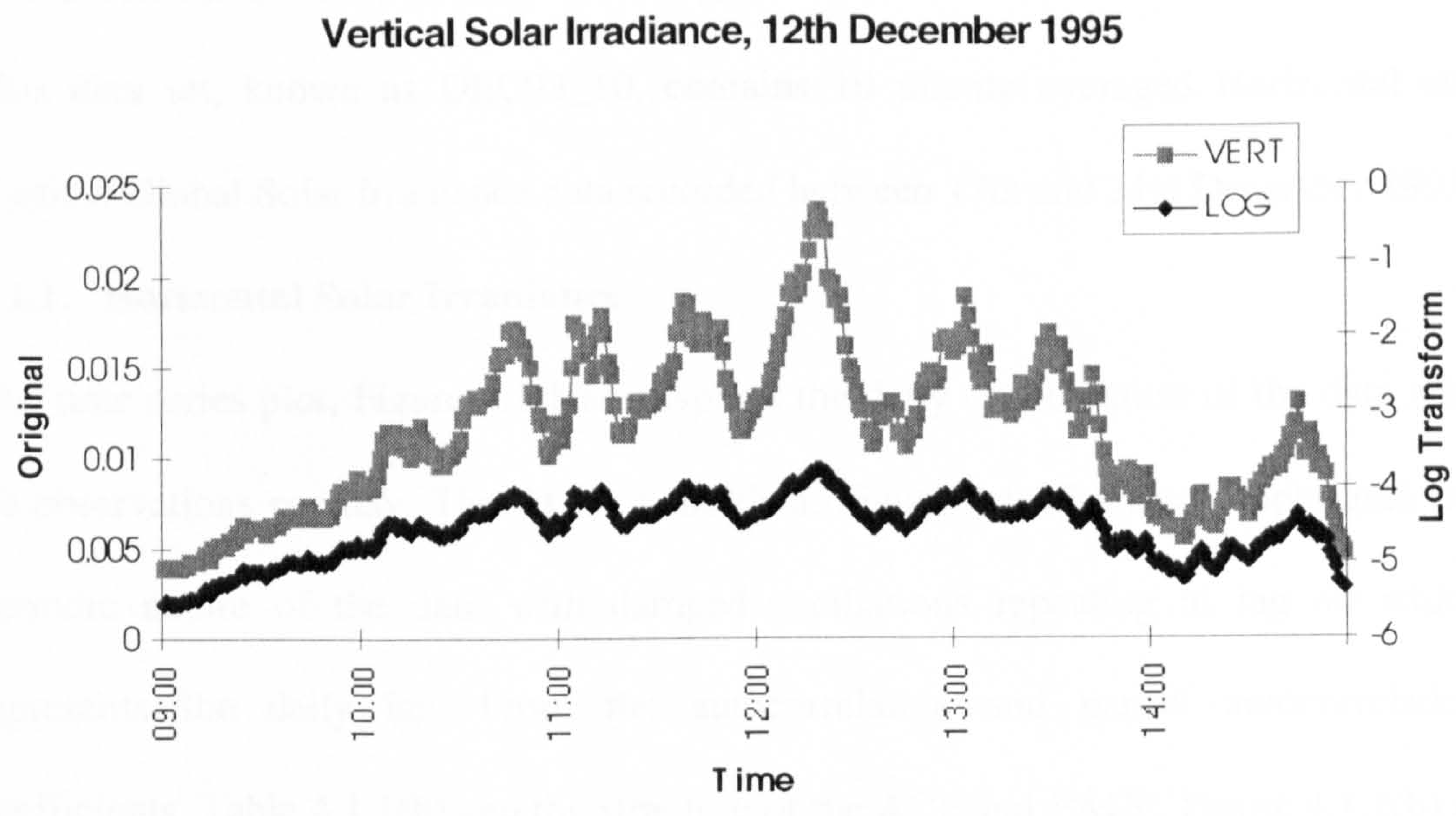


Figure 3.10.4 Vertical Solar Irradiance data, 12th December 1995.



4. Results from Analysis of 10, 20, 30 and 60 minute Averaged Solar Irradiance Data

The following results section contains the analysis of data collected in December 1993, June 1994, December 1994 and June 1995. A full description of the data files are contained in Chapter 2.2. Each data file is divided into four sections corresponding to 10 minute, 20minute, 30 minute and 60 minute, averaged data. Within each section are four sub-sections on Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data. Each sub-section comprises a description of the analysis carried-out, tabulated information on the descriptive statistics, autocorrelation and partial autocorrelation coefficients and a summary of the fitted ARIMA models. Graphs of the time series plots, the structure of the ACF and PACF are also displayed.

4.1. December 1993 - Ten minute averages

This data set, known as DEC93_10, contains 10 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 17th and 31st December 1993.

4.1.1. Horizontal Solar Irradiance

The time series plot, Figure 4.1.1(a), displays the daily cyclic nature of the data with 40 observations per day. The ACF of the data, Figure 4.1.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 40 which represents the daily lag. From the autocorrelation and partial autocorrelation coefficients, Table 4.1.1(b),and the structure of the ACF and PACF, Figure 4.1.1(b) & (c), an ARIMA(2,0,0)(1,0,0)40 model was fitted to the data. This model was found to be appropriate, accounted for 86% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.1.1(b) an ARIMA(1,1,0)(1,0,0)40 model was found to be appropriate, accounted for 85% of the total variance and the ACF of the residuals showed no structure.

4.1.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.1.2(a), displays the daily cyclic nature of the data with 40 observations per day. The ACF of the data, Figure 4.1.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 40. From the autocorrelation and partial autocorrelation coefficients, Table 4.1.2(b) and the structure of the ACF and PACF, Figure 4.1.2(b) & (c), an ARIMA(2,0,0)(1,0,0)40 model was fitted to the data. This model accounted for 89% of the total variance but the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.1.2(b) an ARIMA(1,1,0)(1,0,0)40 model was fitted to the data. This model was found to be appropriate, accounted for 88% of the total variance and the ACF of the residuals showed no structure.

4.1.3. Vertical Solar Irradiance

The time series plot, Figure 4.1.3(a), displays the daily cyclic nature of the data with 40 observations per day. The ACF of the data, Figure 4.1.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 40. From the autocorrelation and partial autocorrelation coefficients, Table 4.1.3(b) and the structure of the ACF and PACF, Figure 4.1.3(b) & (c), an ARIMA(2,0,0)(1,0,0)40 model was fitted to the data. This model was found to be appropriate, accounted for 84% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.1.3(b) an ARIMA(2,1,0)(1,0,0)40 model was fitted to the data. This model was found to be appropriate, accounted for 83% of the total variance and the ACF of the residuals showed no structure.

4.1.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.1.4(a), displays the daily cyclic nature of the data with 40 observations per day. The ACF of the data, Figure 4.1.4(b) also emphasises the periodic nature of the data with damped oscillations repeating at lag 40. From the autocorrelation and partial autocorrelation coefficients, Table 4.1.4(b) and the structure of the ACF and PACF, Figure 4.1.4(b) & (c), an ARIMA(2,0,0)(1,0,0)40 model was fitted to the data. This model was found to be appropriate, accounted for 87% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.1.4(b) an ARIMA(1,1,0)(1,0,0)40 model was fitted to the data. This model was found to be appropriate, accounted for 87% of the total variance and the ACF of the residuals showed no structure.

Table 4.1.1 Summary information for Horizontal Solar Irradiance - 10 minute averages (datafile DEC93_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0679	0.0522	0.00210	0.2067

b)

$2/\sqrt{600}=0.082$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.925	0.925	0.115	0.115
2	0.834	-0.151	-0.035	-0.049
3	0.749	0.001	0.018	0.027
4	0.661	-0.076	-0.048	-0.056
40	0.442	0.013	0.100	0.024

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,0,0)(1,0,0)40	AR1	1.0655	0.0406	26.22	0.2218	0.000372	86
	AR2	-0.1537	0.0405	-3.79			
	SAR40	0.1019	0.0414	2.46			
	CONST	0.00528	0.0008	6.70			
ARIMA(1,1,0)(1,0,0)40	AR1	0.1030	0.0408	2.53	0.23359	0.000391	85
	SAR40	0.0880	0.0413	2.13			

Table 4.1.2 Summary information for Log Transformed Horizontal Solar Irradiance - 10 minute averages (datafile DEC93_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0589	0.9578	-6.1658	-1.5765

b)

$2/\sqrt{600}=0.082$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.925	0.925	0.213	0.213
2	0.822	-0.233	0.020	-0.027
3	0.718	-0.032	-0.013	-0.012
4	0.617	-0.044	0.000	0.006
40	0.600	0.001	0.386	0.297

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)(1,0,0)40	AR1	1.1133	0.0401	27.77	58.9325	0.0989	89
	AR2	-0.2245	0.0399	-5.63			
	SAR40	0.4227	0.0381	11.08			
	CONST	-0.1970	0.01285	-15.34			
ARIMA(1,1,0)(1,0,0)40	AR1	0.1719	0.0404	4.25	63.4710	0.1063	88
	SAR40	0.3966	0.0384	10.33			

Table 4.1.3 Summary information for Vertical Solar Irradiance - 10 minute averages (datafile DEC93_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1674	0.2189	0.0013	0.7675

b)

$2/\sqrt{600}=0.082$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.913	0.913	0.086	0.086
2	0.811	-0.132	-0.118	-0.127
3	0.729	0.076	-0.042	-0.020
4	0.655	-0.026	-0.078	-0.089
40	0.219	0.027	0.020	0.002

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)(1,0,0)40	AR1	1.0354	0.0406	25.50	4.68124	0.00785	84
	AR2	-0.1352	0.0406	-3.33			
	SAR40	0.0378	0.0417	0.91			
	CONST	0.01577	0.00362	4.36			
ARIMA(2,1,0)(1,0,0)40	AR1	0.0958	0.0407	2.36	4.87291	0.00818	83
	AR2	-0.1268	0.0407	-3.12			
	SAR40	0.0224	0.0416	0.54			

Table 4.1.4 Summary information for Log TraSolar Irradiaırtical Solar Irradiance - 10 minute averages (datafile DEC¶tive Statistic)escriptive Statistics; b) Autocorrelation and Partial Autocents; c) Sumefficients; c) Summary information on fitted ARIMA mod‹

a)

mean	std. dev.	maximum	maximum
-2.8432	1.5852	-0.2646	-0.2646

b)

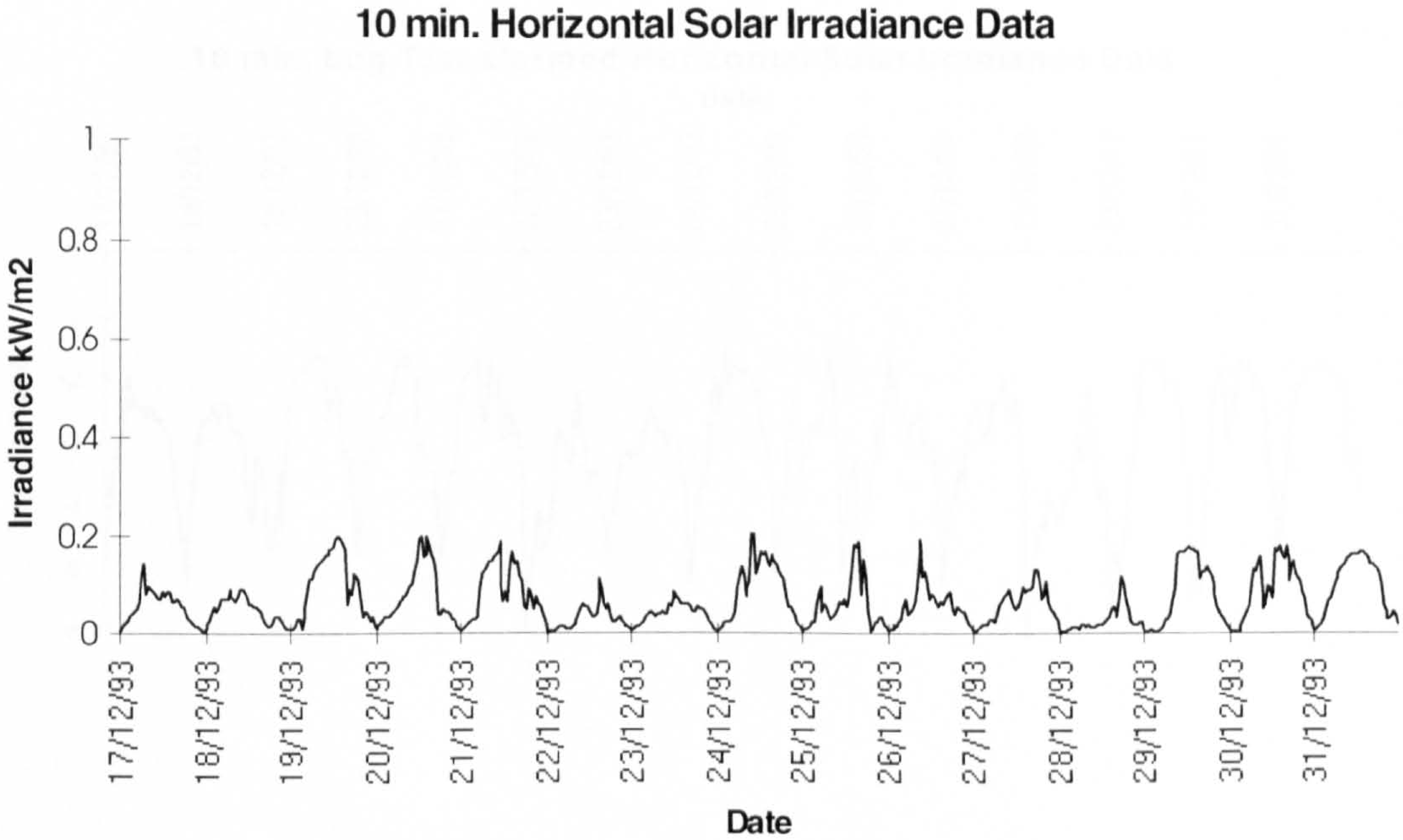
2/√600=0.082	Original			›renced
lag	ACF	PACF	ɜ	PACF
1	0.928	0.928	.	0.171
2	0.832	-0.207	9	-0.069
3	0.741	0.018	4	-0.004
4	0.655	-0.043	7	-0.057
40	0.333	0.010	;	0.165

c)

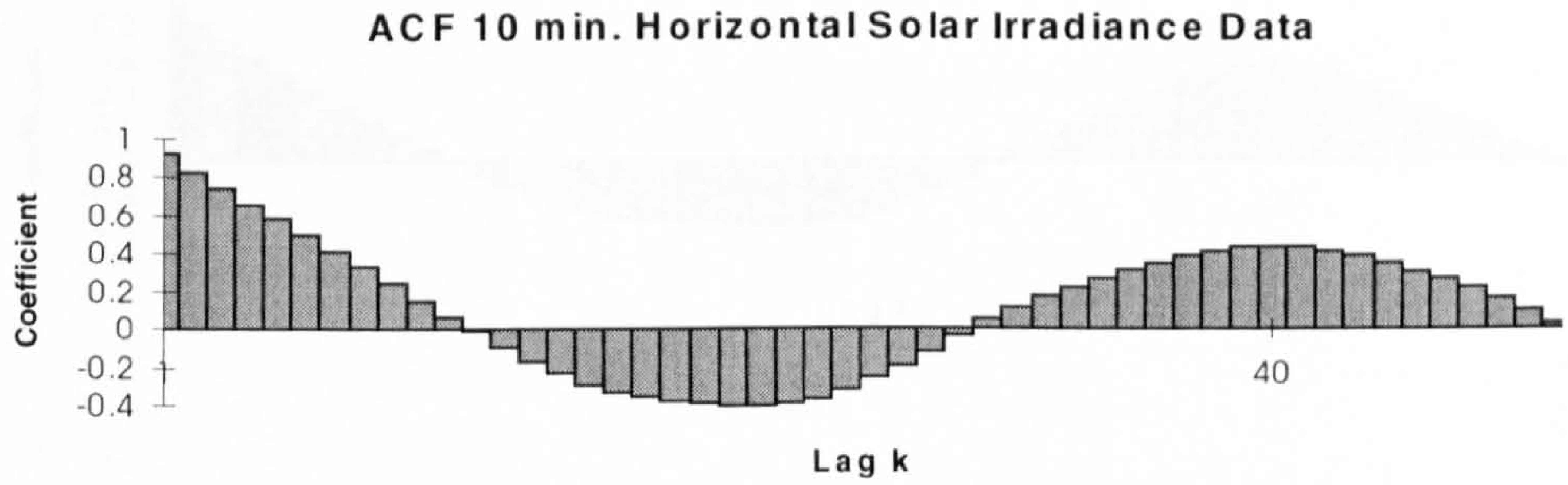
model	parameter	estimate	std. d	MS	SS	MS	$R^2\%$
ARIMA(2,0,0)(1,0,0)40	AR1	1.1223	0.04‹3	0.315	187.833	0.315	87
	AR2	-0.2138	0.04‹				
	SAR40	0.2183	0.04‹				
	CONST	-0.20408	0.022				
ARIMA(1,1,0)(1,0,0)40	AR1	0.1643	0.04‹3	0.334	199.373	0.334	87
	SAR40	0.2050	0.04‹				
ARIMA(2,1,0)(1,0,0)40	AR1	0.1783	0.04‹6	0. !	197.846	0.332	87
	AR2	-0.0879	0.04‹				
	SAR40	0.2129	0.04‹				

Figure 4.1.1 Horizontal Solar Irradiance - 10 minute averages, DEC93_10

a)



b)



c)

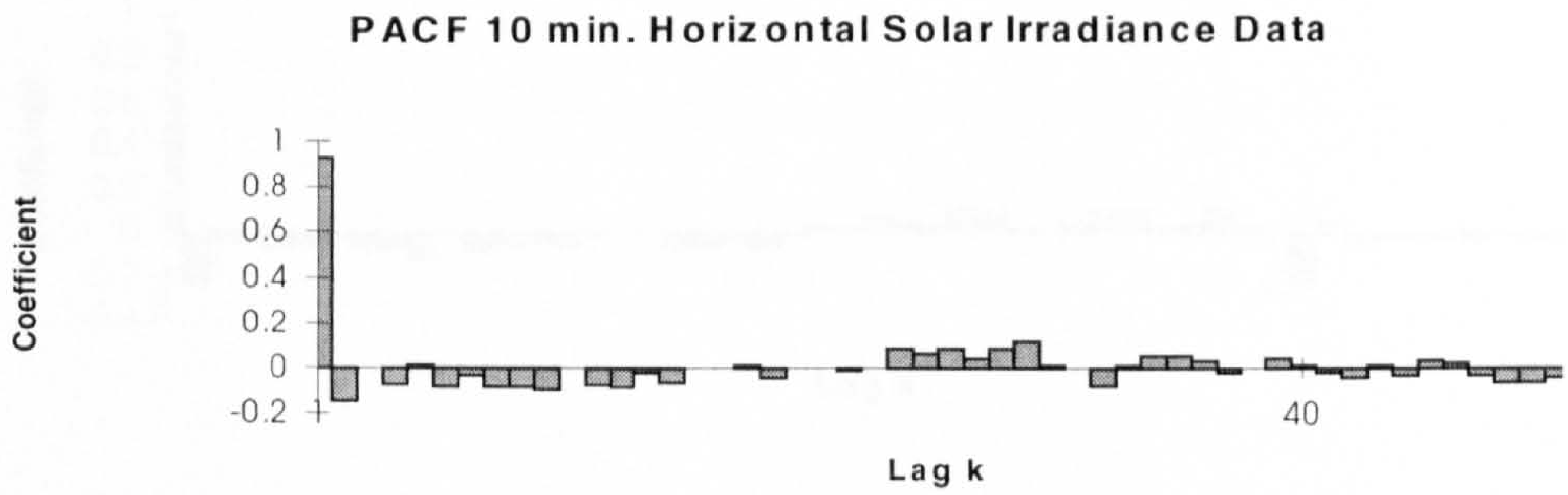
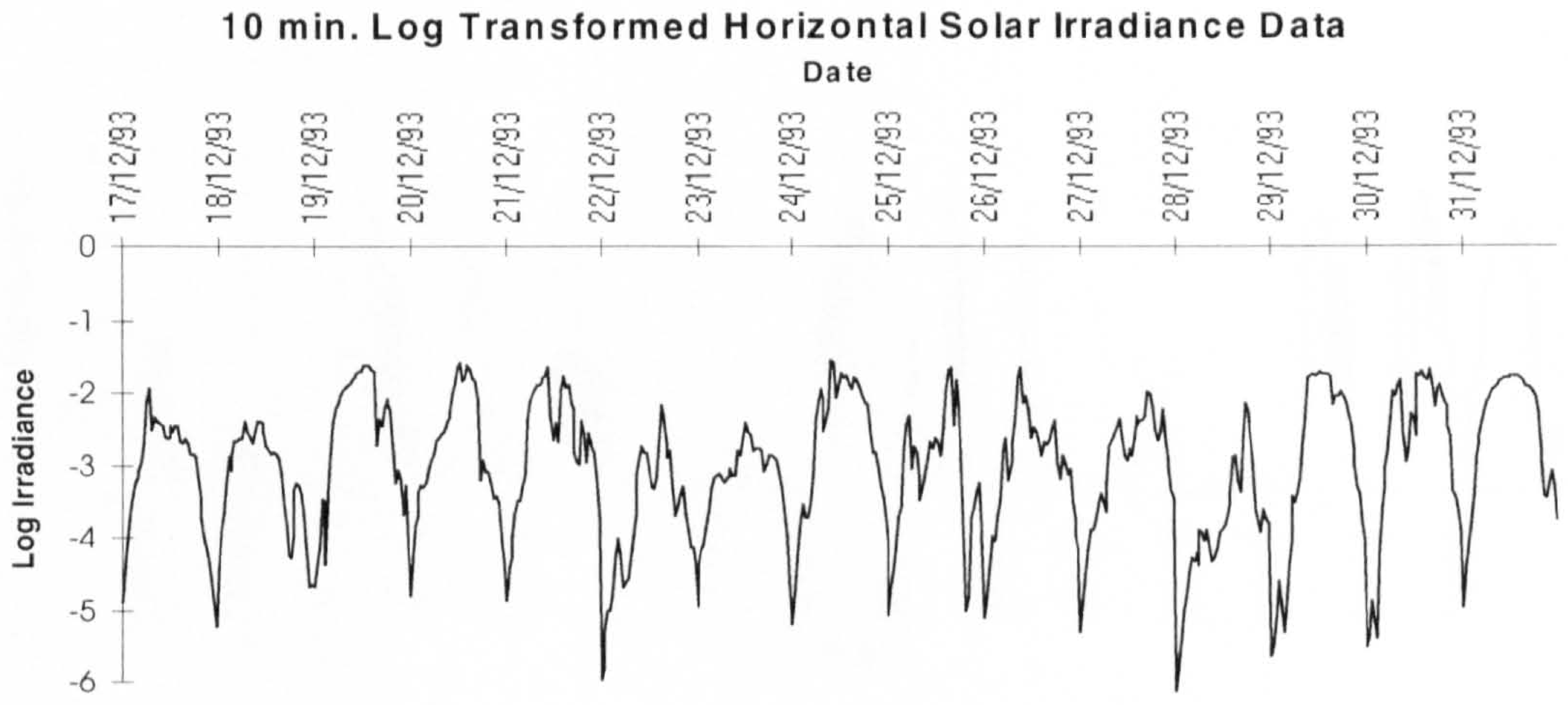
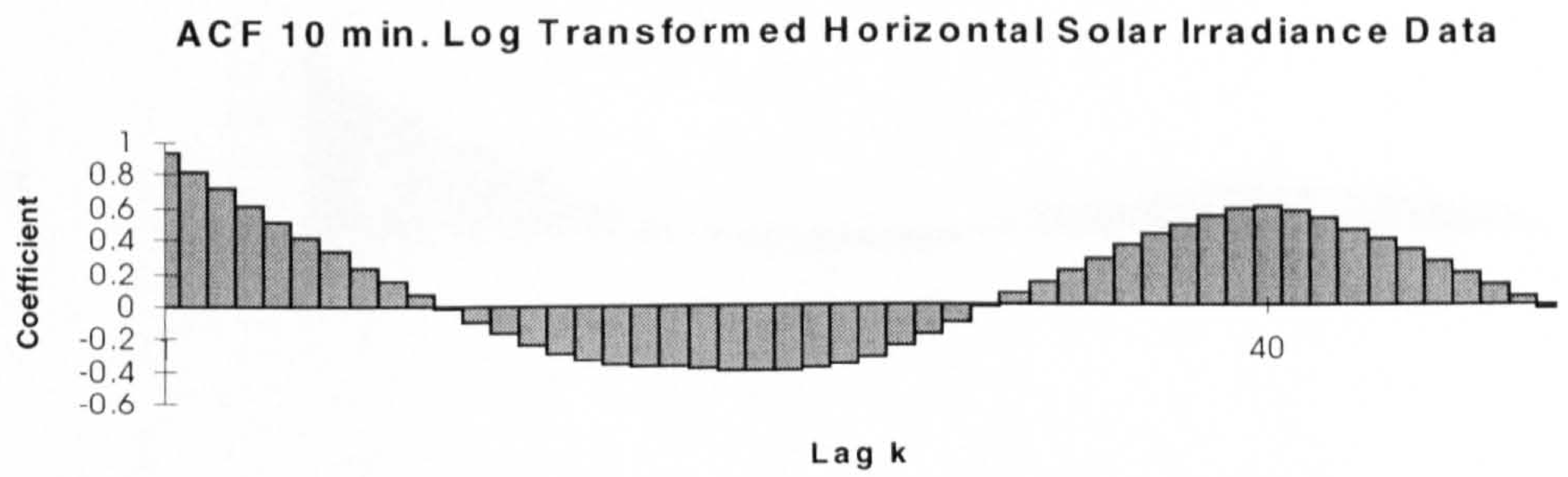


Figure 4.1.2 Log transformed Horizontal Solar Irradiance - 10 minute averages, DEC93_10

a)



b)



c)

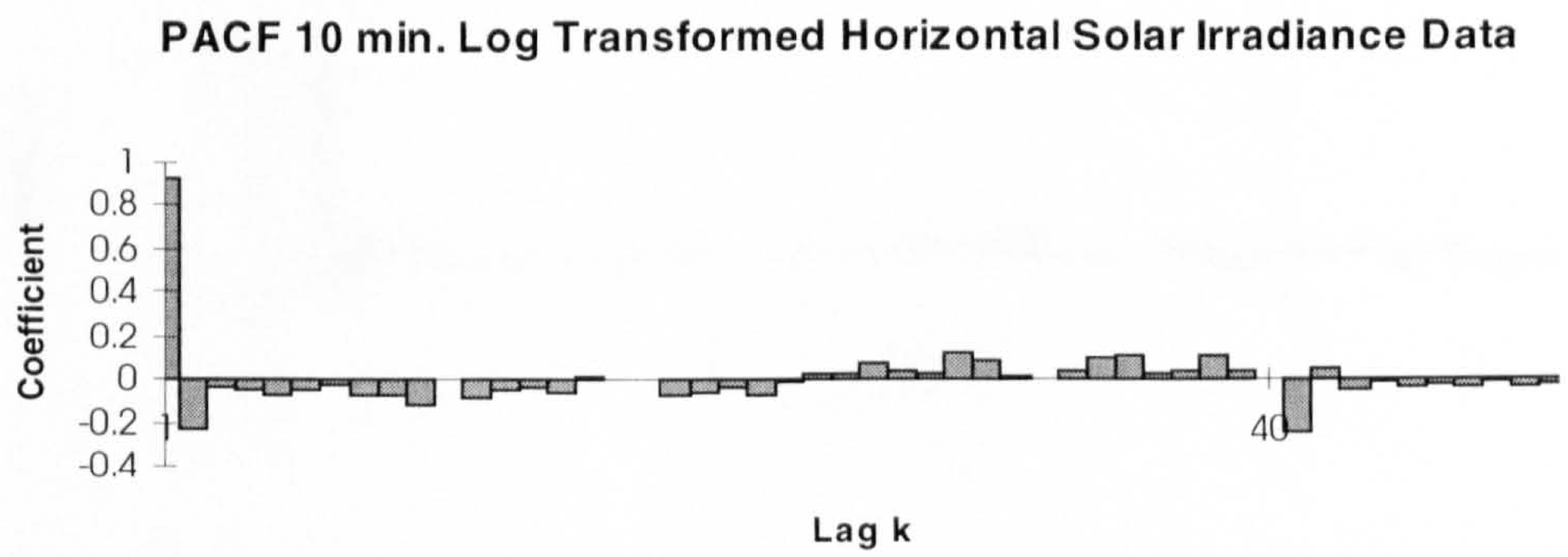
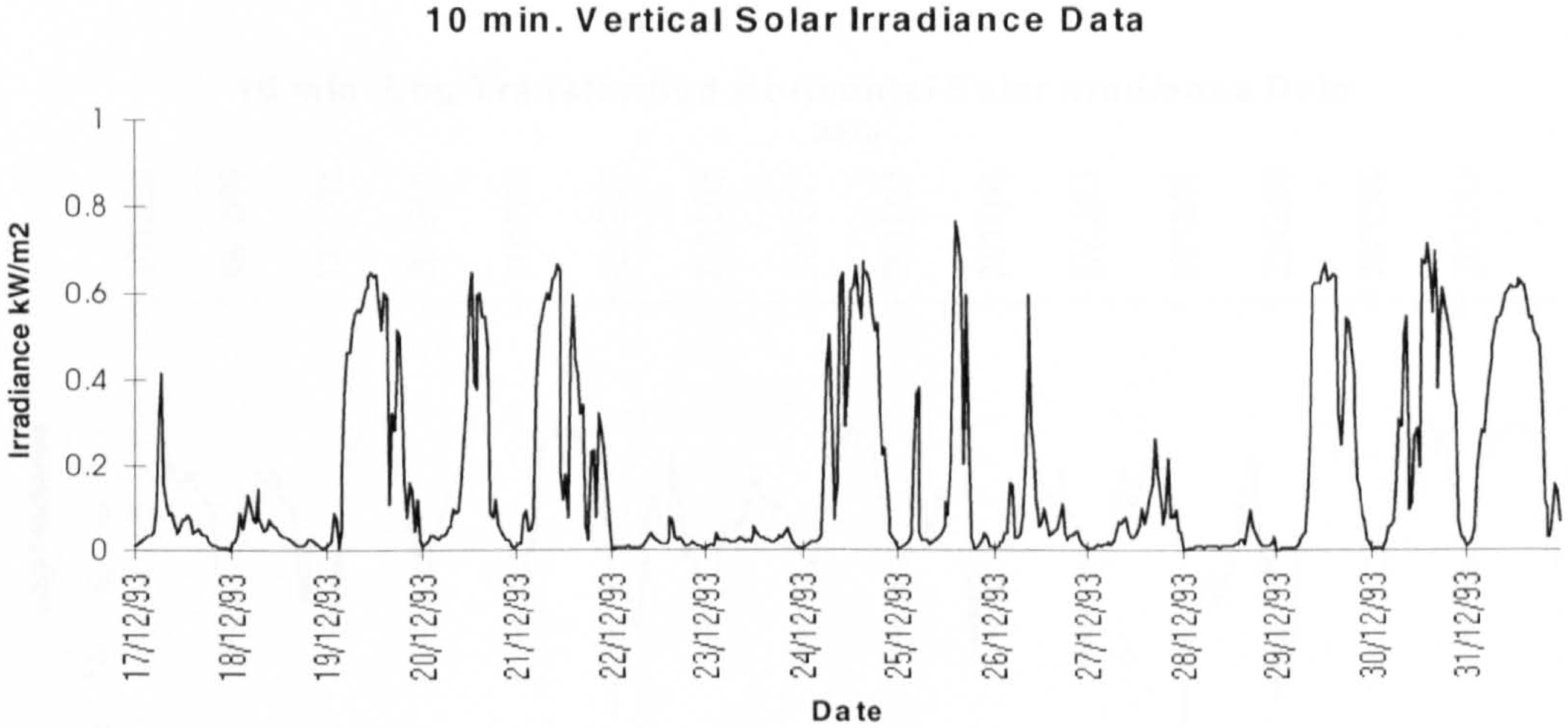
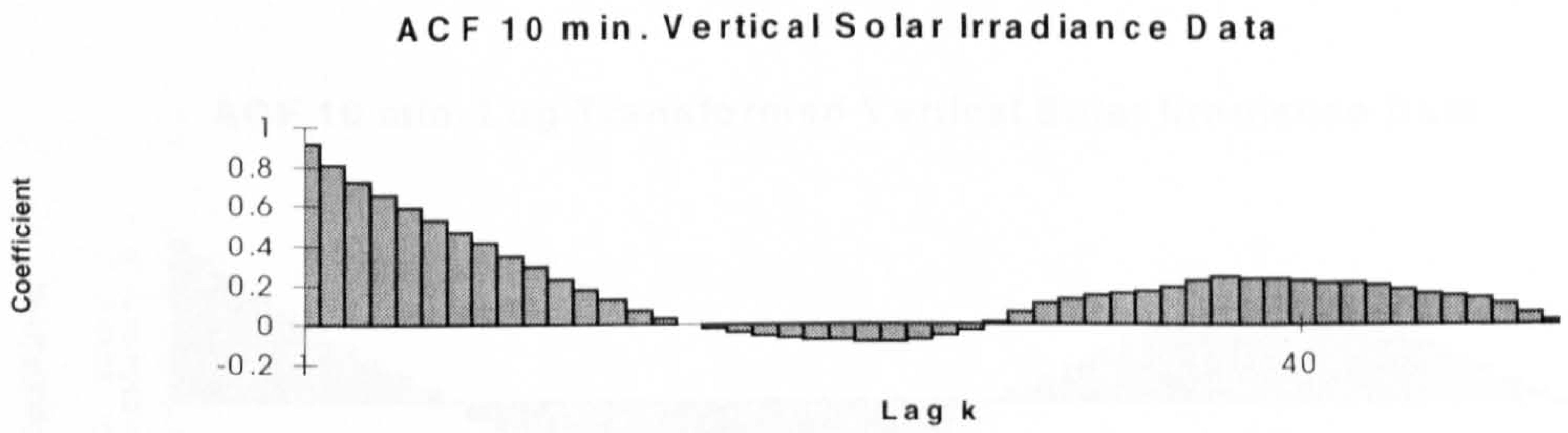


Figure 4.1.3 Vertical Solar Irradiance - 10 minute averages, DEC93_10

a)



b)



c)

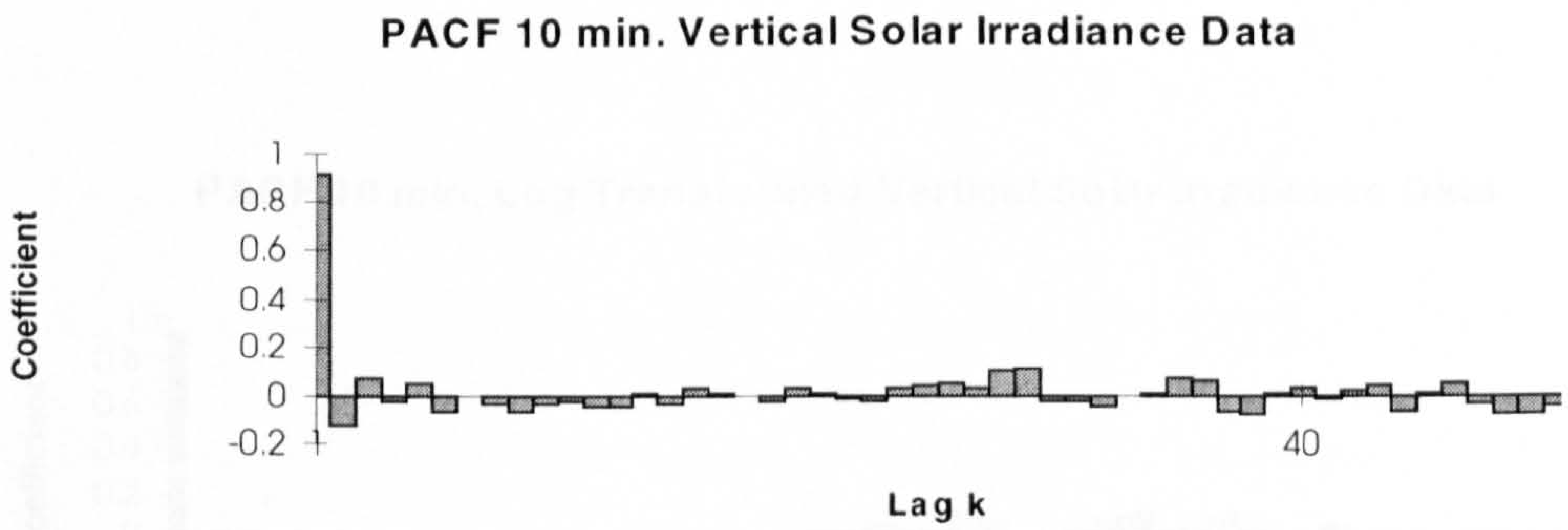
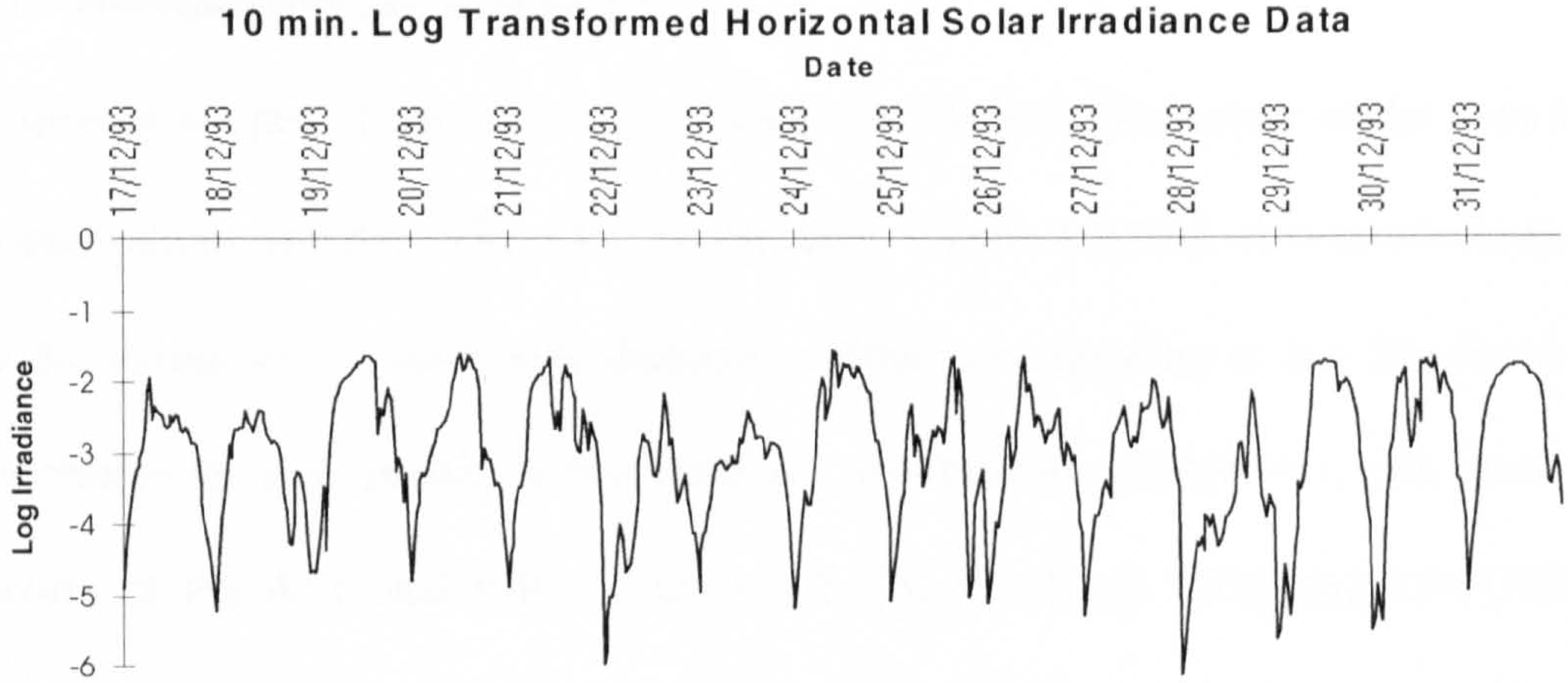
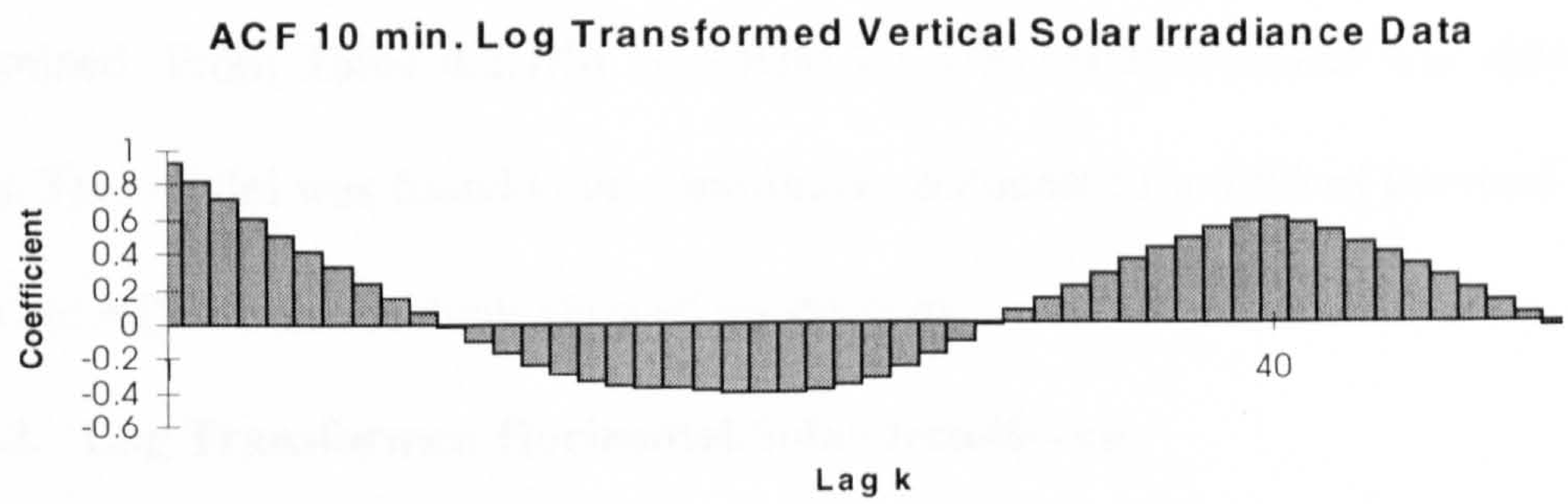


Figure 4.1.4 Log transformed Vertical Solar Irradiance - 10 minute averages, DEC93_10

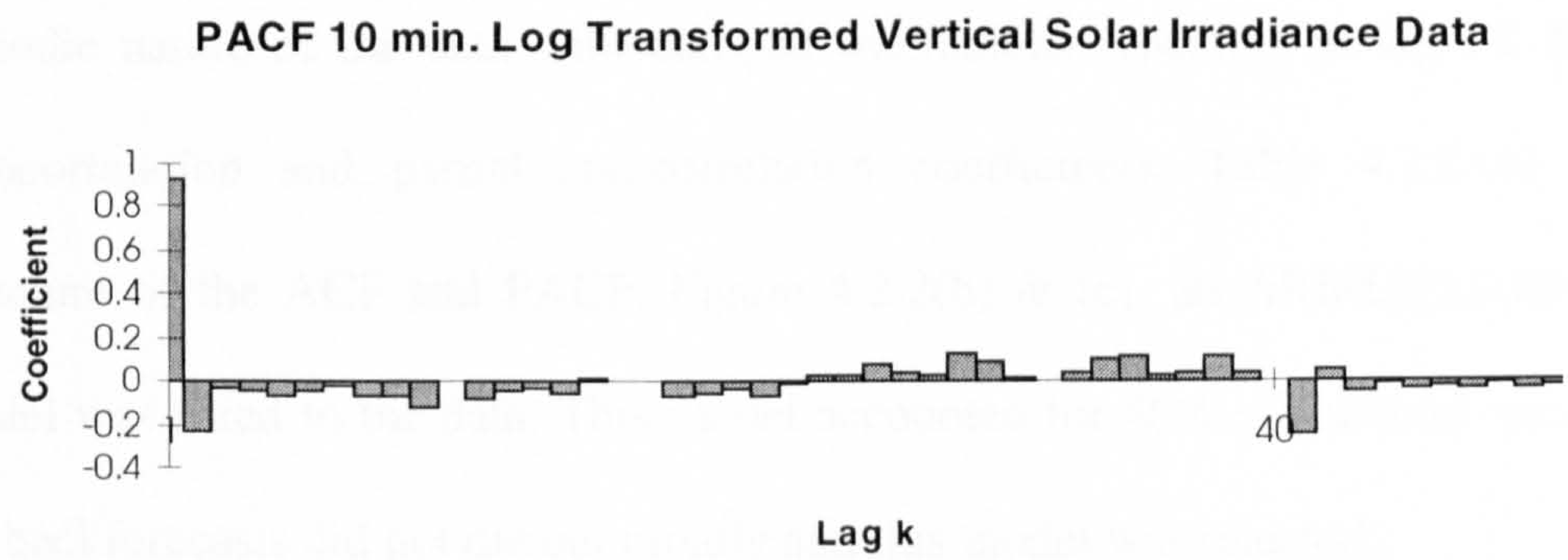
a)



b)



c)



4.2. December 1993 - Twenty minute averages

This data set, known as DEC93_20, contains 20 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 17th and 31st December 1993.

4.2.1. Horizontal Solar Irradiance

The time series plot, Figure 4.2.1(a), displays the daily cyclic nature of the data with 20 observations per day. The ACF of the data, Figure 4.2.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 20. From the autocorrelation and partial autocorrelation coefficients, Table 4.2.1(b), and the structure of the ACF and PACF, Figure 4.2.1(b) & (c), an ARIMA(2,0,0)(1,0,0)20 model was fitted to the data. This model was found to be appropriate, accounted for 77% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.2.1(b) an ARIMA(1,1,0)(1,0,0)20 model was fitted to the data. This model was found to be appropriate, accounted for 77% of the total variance and the ACF of the residuals showed no structure.

4.2.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.2.2(a), displays the daily cyclic nature of the data with 20 observations per day. The ACF of the data, Figure 4.2.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 20. From the autocorrelation and partial autocorrelation coefficients, Table 4.2.2.(b) and the structure of the ACF and PACF, Figure 4.2.2(b) & (c), an ARIMA(2,0,0)(1,0,0)20 model was fitted to the data. This model accounted for 80% of the total variance but the backforecasts did not die out rapidly and this model was rejected..

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.2.2(b) an ARIMA(1,1,0)(1,0,0)20 model was fitted to the data. This model was found to be appropriate, accounted for 77% of the total variance and the ACF of the residuals showed no structure.

4.2.3. Vertical Solar Irradiance

The time series plot, Figure 4.2.3(a), displays the daily cyclic nature of the data with 20 observations per day. The ACF of the data, Figure 4.2.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 20. From the autocorrelation and partial autocorrelation coefficients, Table 4.2.3.(b), and the structure of the ACF and PACF, Figure 4.2.3(b) & (c), an ARIMA(1,0,0)(1,0,0)20 model was fitted to the data. This model was found to be appropriate, accounted for 72% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.2.3(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

4.2.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.2.4 (a), displays the daily cyclic nature of the data with 20 observations per day. The ACF of the data, Figure 4.2.4 (b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 20. From the autocorrelation and partial autocorrelation coefficients, Table 4.2.4.(b), and the structure of the ACF and PACF, Figure 4.2.4 (b) & (c), an ARIMA(2,0,0)(1,0,0)20 model was fitted to the data. This model was found to be appropriate, accounted for 77% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.2.4(b) an ARIMA(2,1,0)(1,0,0)20 model was fitted to the data. This model was found to be appropriate, accounted for 75% of the total variance and the ACF of the residuals showed no structure. It was found that an ARIMA(1,1,0)(1,0,0)20 model was also appropriate, accounted for 74% of the total variance and the ACF of the residuals showed no structure.

Table 4.2.1 Summary Information for Horizontal Solar Irradiance - 20 minute averages (datafile DEC93_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0679	0.0513	0.0025	0.2055

b)

$2/\sqrt{300} = 0.115$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.864	0.864	0.146	0.146
2	0.690	-0.220	-0.013	-0.035
3	0.520	-0.070	0.044	0.052
4	0.340	-0.160	0.040	0.026
20	0.458	0.065	0.216	0.073

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)(1,0,0)20	AR1	1.0203	0.0575	17.74	0.1779	0.000601	77
	AR2	-0.1923	0.0572	-3.36			
	SAR20	0.2203	0.0583	3.78			
	CONST	0.00923	0.00141	6.52			
ARIMA(1,1,0)(1,0,0)20	AR1	0.1006	0.0580	1.73	0.1978	0.000666	77
	SAR20	0.2066	0.0582	3.55			
ARIMA(1,0,0)(1,0,0)20	AR1	0.8302	0.0311	26.65	0.1833	0.000617	76
	SAR20	0.2644	0.0574	4.60			
	CONST	0.0086	0.0014	6.02			

Table 4.2.2 Summary Information for Log Transformed Horizontal Solar Irradiance - 20 minute averages (datafile DEC93_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0472	0.9423	-5.9717	-1.5821

b)

$2/\sqrt{300} = 0.115$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.843	0.843	0.186	0.186
2	0.634	-0.264	-0.015	-0.051
3	0.432	-0.078	-0.053	-0.042
4	0.248	-0.086	0.006	0.024
20	0.609	0.094	0.470	0.311

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)(1,0,0)20	AR1	0.9773	0.0571	17.11	52.1414	0.1762	80
	AR2	-0.2056	0.0567	-3.62			
	SAR20	0.5148	0.0513	10.03			
	CONST	-0.3368	0.02425	-13.89			
ARIMA(1,1,0)(1,0,0)20	AR1	0.0939	0.0580	1.62	60.046	0.2022	77
	SAR20	0.4997	0.0516	9.68			
ARIMA(1,0,0)(1,0,0)20	AR1	0.8082	0.0344	23.52	54.3588	0.1830	79
	SAR20	0.5418	0.0502	10.79			
	CONST	-0.2681	0.0247	-10.84			

Table 4.2.3 Summary Information for Vertical Solar Irradiance - 20 minute averages (datafile DEC93_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1674	0.2141	0.0016	0.7513

b)

$2/\sqrt{300} = 0.115$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.848	0.848	0.001	0.001
2	0.696	-0.082	-0.064	-0.064
3	0.563	-0.022	0.009	0.009
4	0.428	-0.094	-0.013	-0.017
20	0.230	-0.022	0.018	-0.049

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)20	AR1	0.8473	0.0310	27.33	3.8162	0.01285	72
	SAR21	0.0403	0.0598	0.67			
	CONST	0.0240	0.0065	3.67			

Table 4.2.4 Summary Information for Log Transformed Vertical Solar Irradiance - 20 minute averages (datafile DEC93_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.8081	1.5683	-6.4378	-0.2860

b)

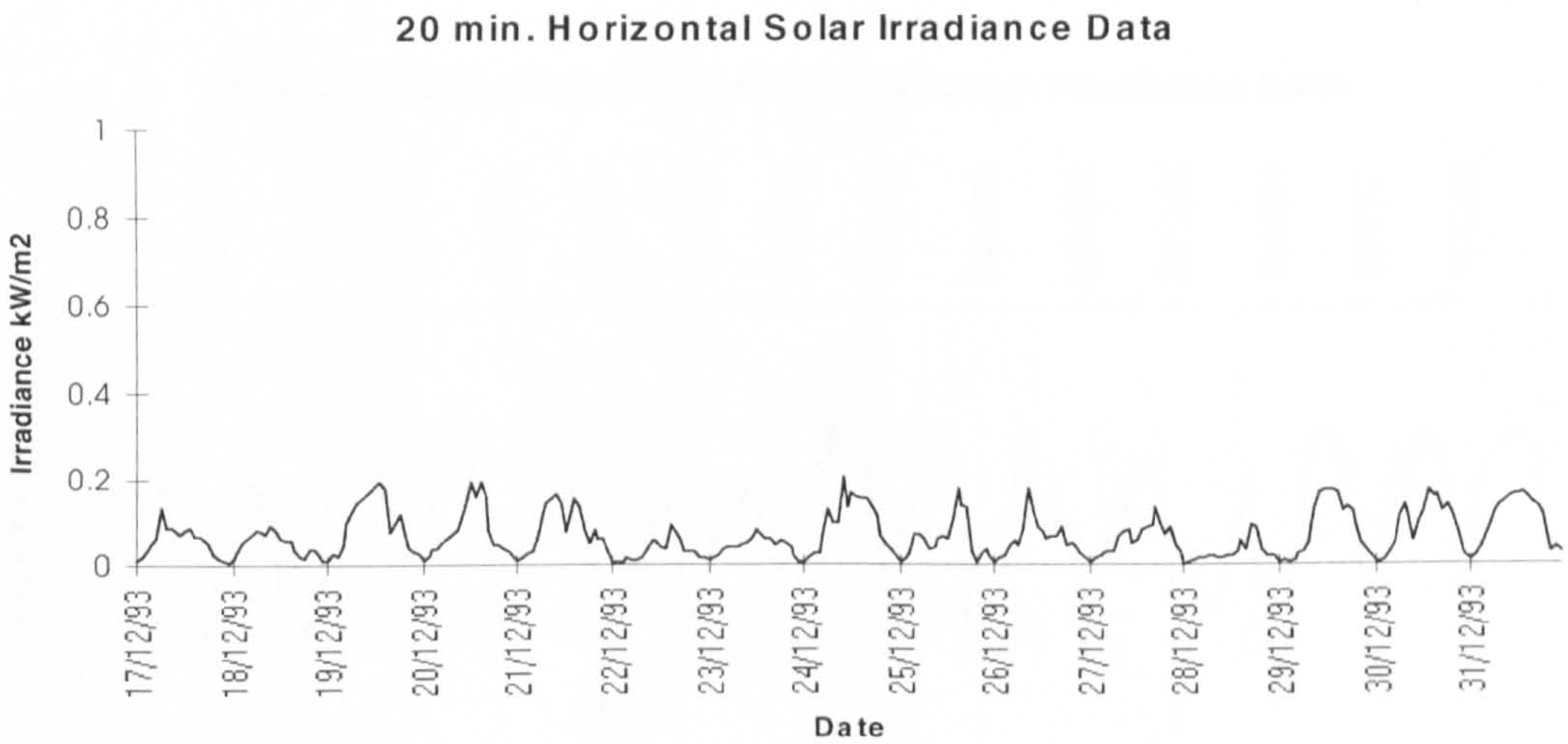
$2/\sqrt{300} = 0.115$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.859	0.859	0.151	0.151
2	0.677	-0.229	-0.092	-0.117
3	0.523	0.020	-0.076	-0.045
4	0.389	-0.052	-0.030	-0.022
20	0.333	0.005	0.248	0.141

c)

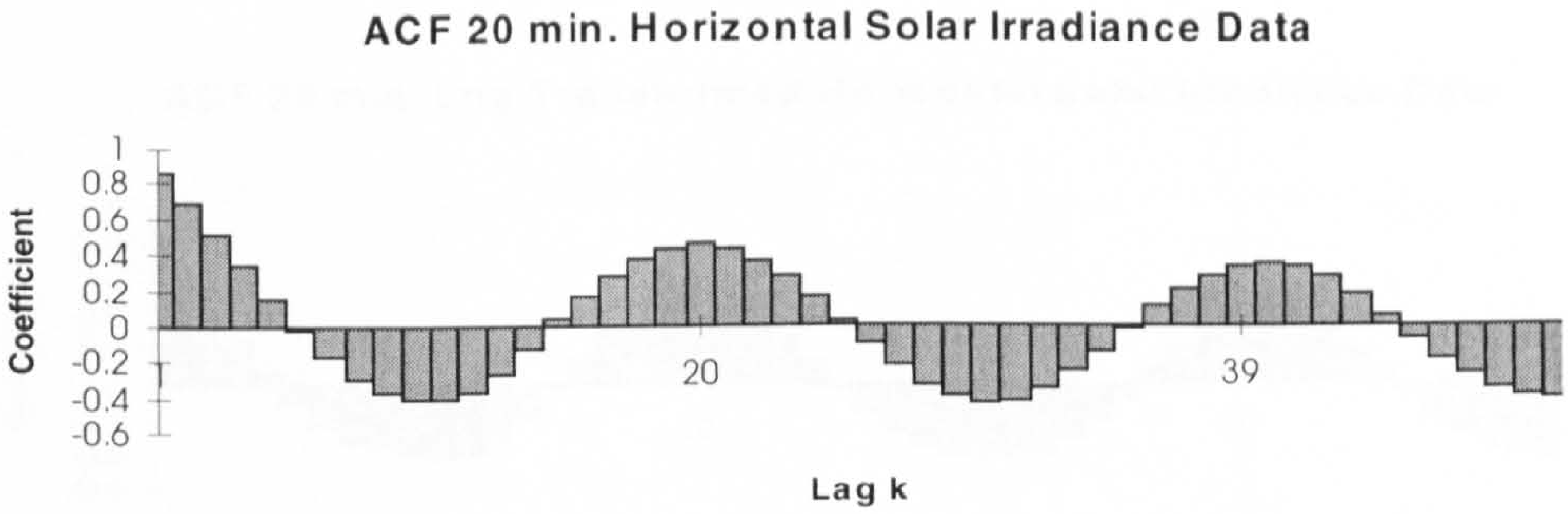
model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,0,0)(1,0,0)20	AR1	1.0424	0.0568	18.34	167.132	0.565	77
	AR2	-0.2207	0.0566	-3.90			
	SAR21	0.2706	0.0576	4.69			
	CONST	-0.3643	0.0434	-8.39			
ARIMA(2,1,0)(1,0,0)20	AR1	0.1505	0.0574	2.62	181.987	0.615	75
	AR2	-0.1604	0.0584	-2.75			
	SAR20	0.2890	0.0577	5.01			
ARIMA(1,1,0)(1,0,0)20	AR1	0.1316	0.0576	2.28	186.761	0.629	74
	SAR20	0.2649	0.0575	4.60			
ARIMA(1,0,0)(1,0,0)20	AR1	0.8539	0.0304	28.09	175.662	0.591	76
	SAR20	0.2849	0.0572	4.98			
	CONST	-0.2928	0.0444	-6.59			

Figure 4.2.1 Horizontal Solar Irradiance - 20 minute averages, DEC93_20

a)



b)



c)

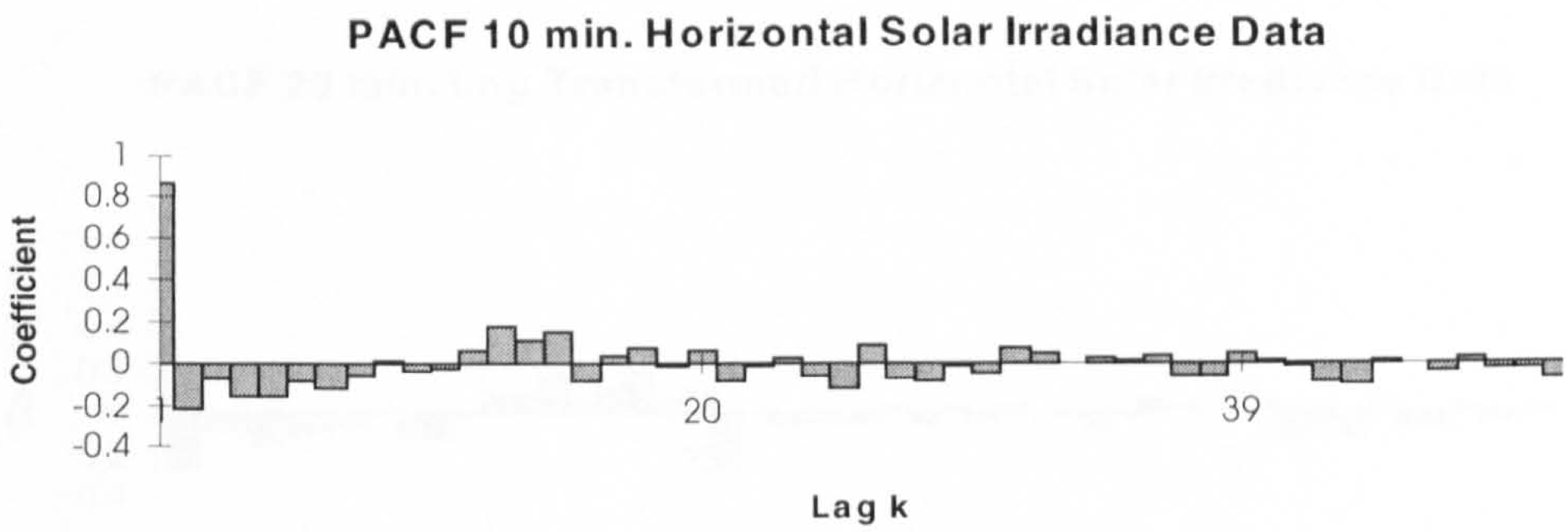
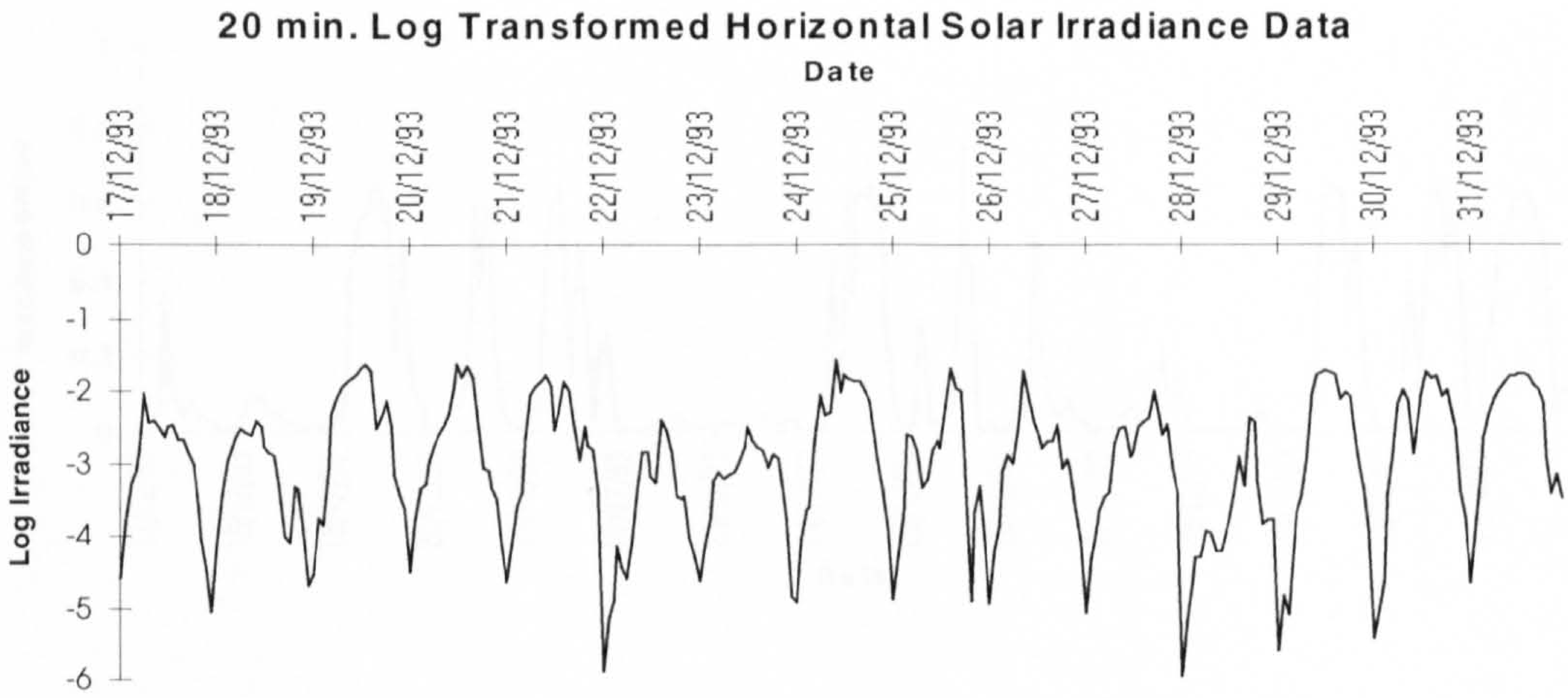
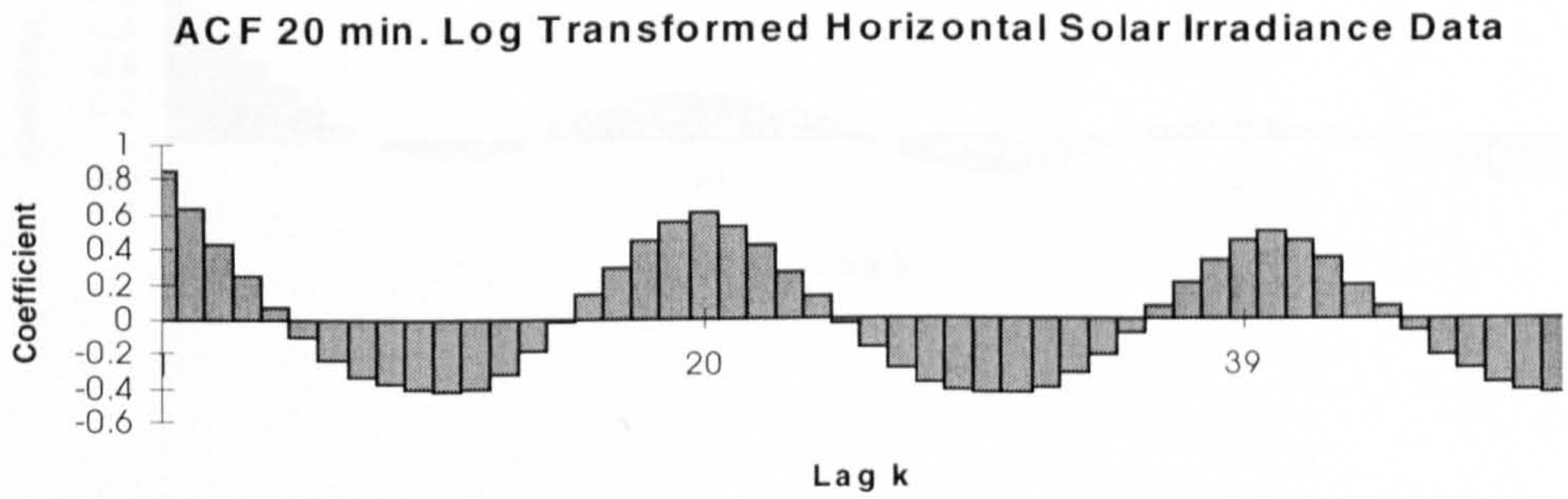


Figure 4.2.2 Log transformed Horizontal Solar Irradiance - 20 minute averages, DEC93_20

a)



b)



c)

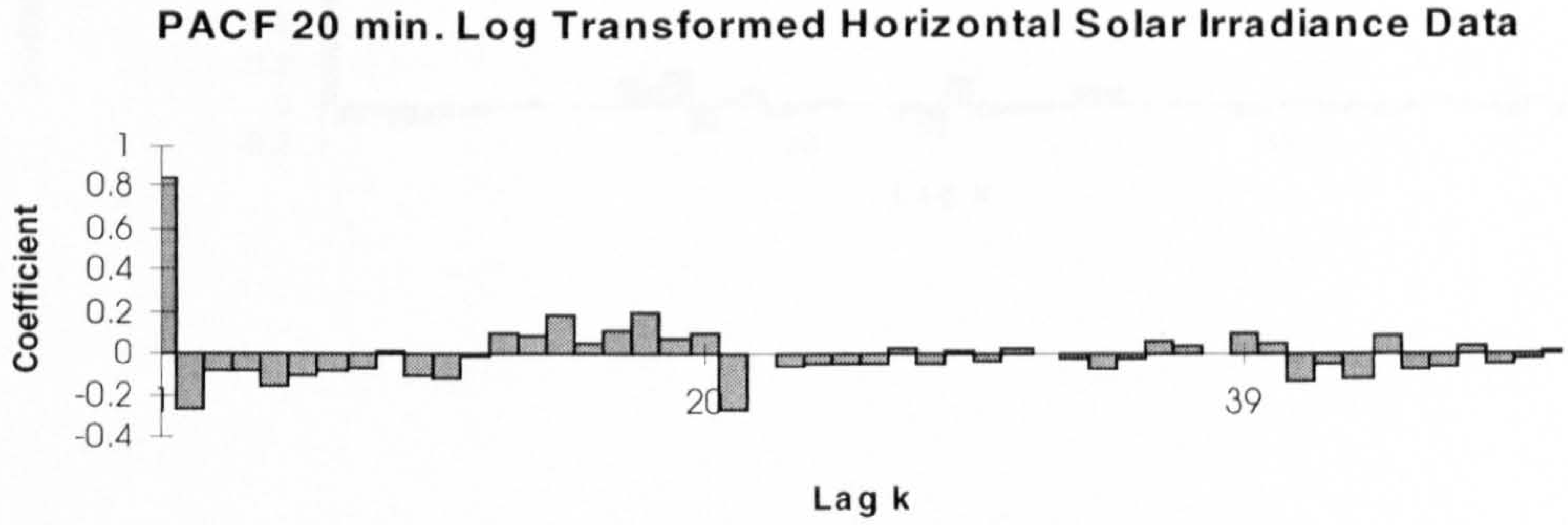
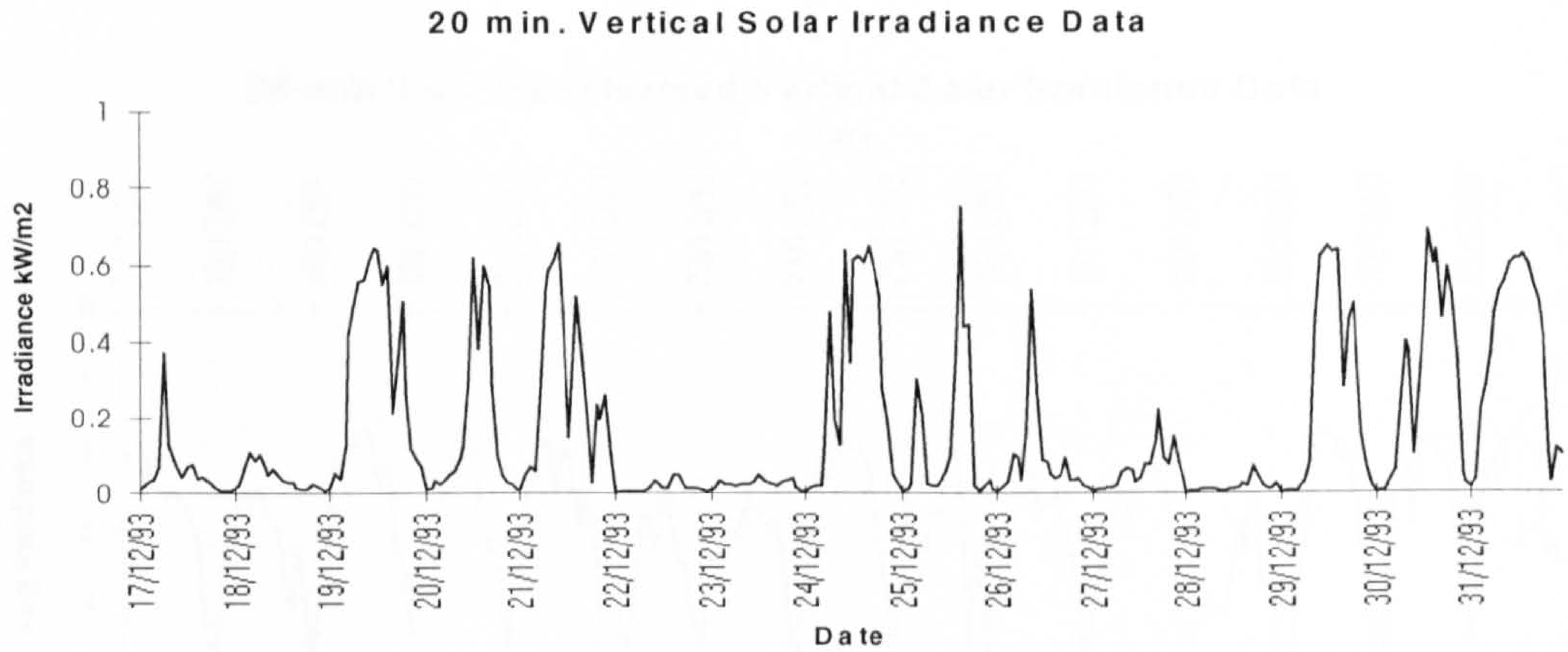
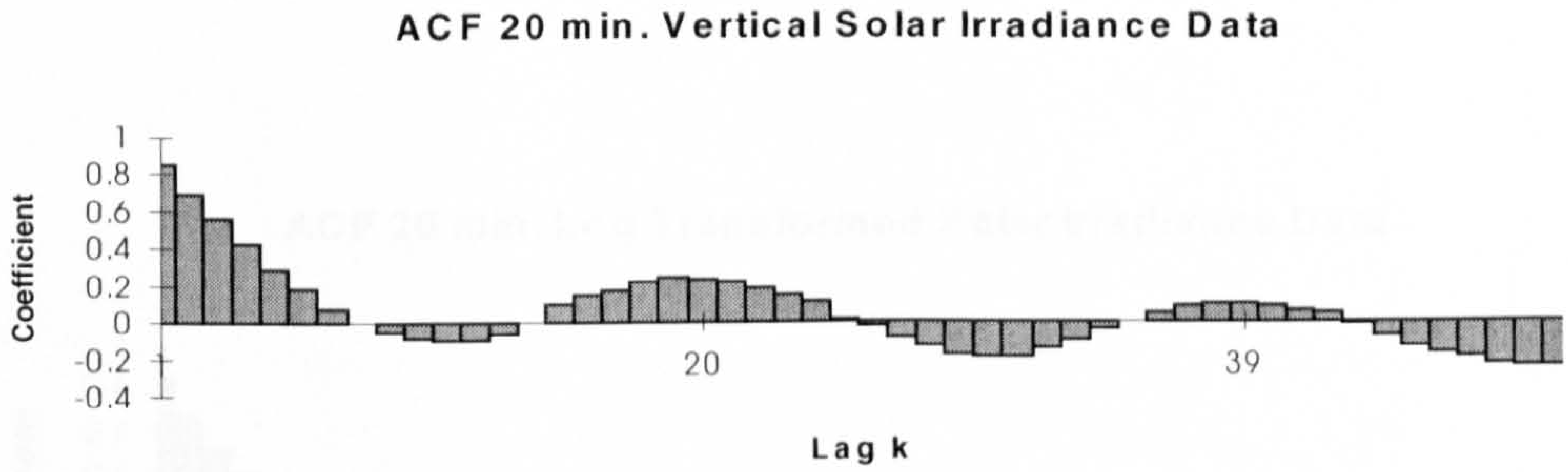


Figure 4.2.3 Vertical Solar Irradiance - 20 minute averages, DEC93_20

a)



b)



c)

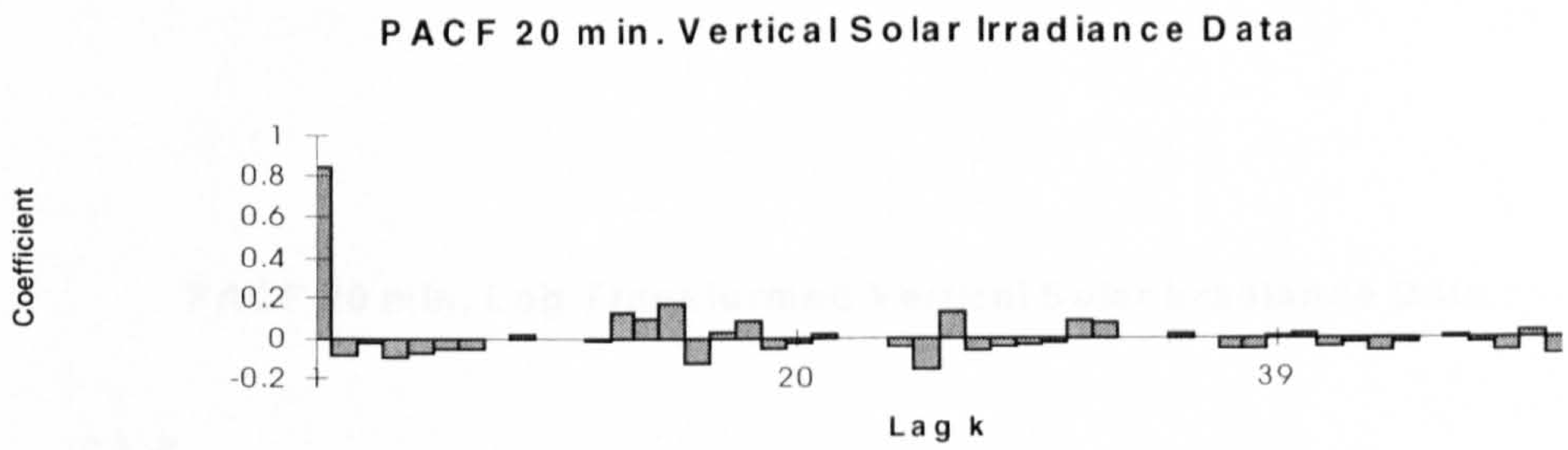
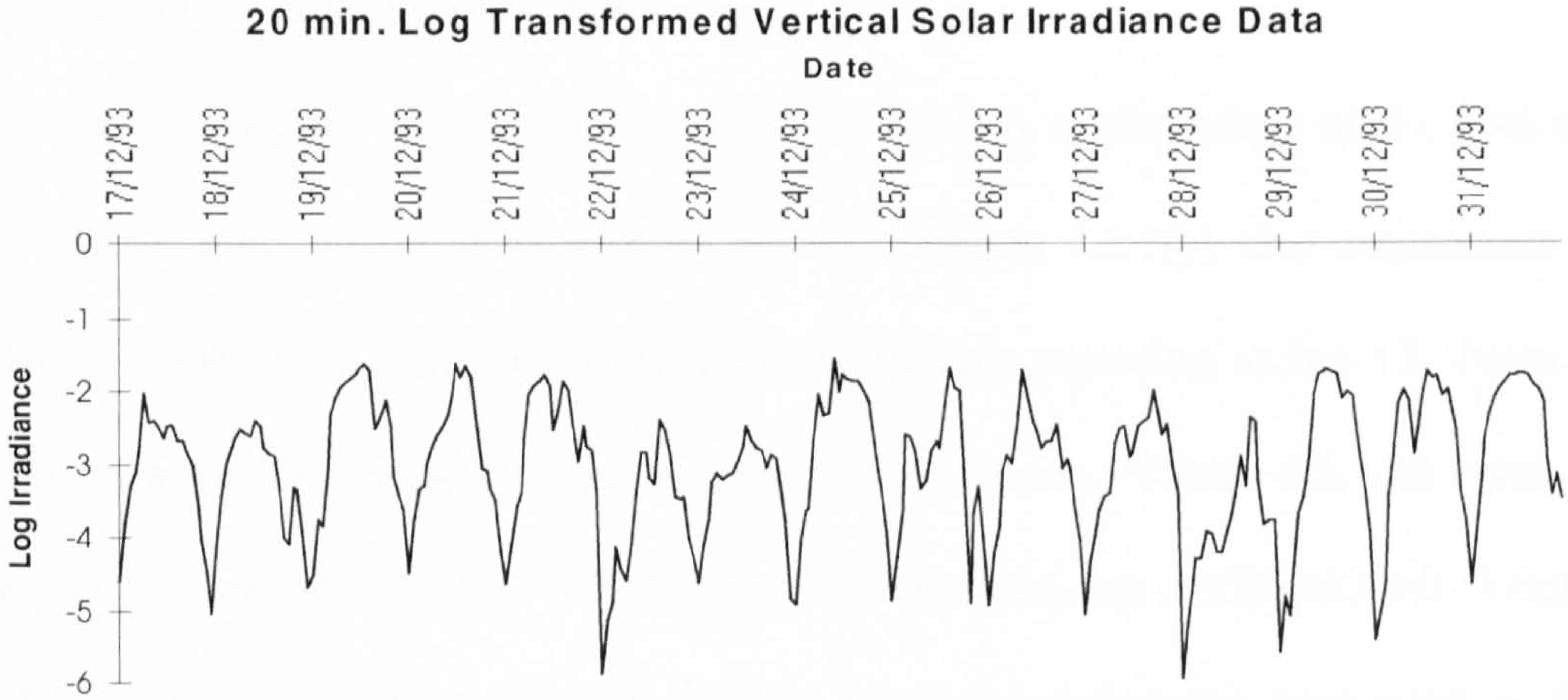
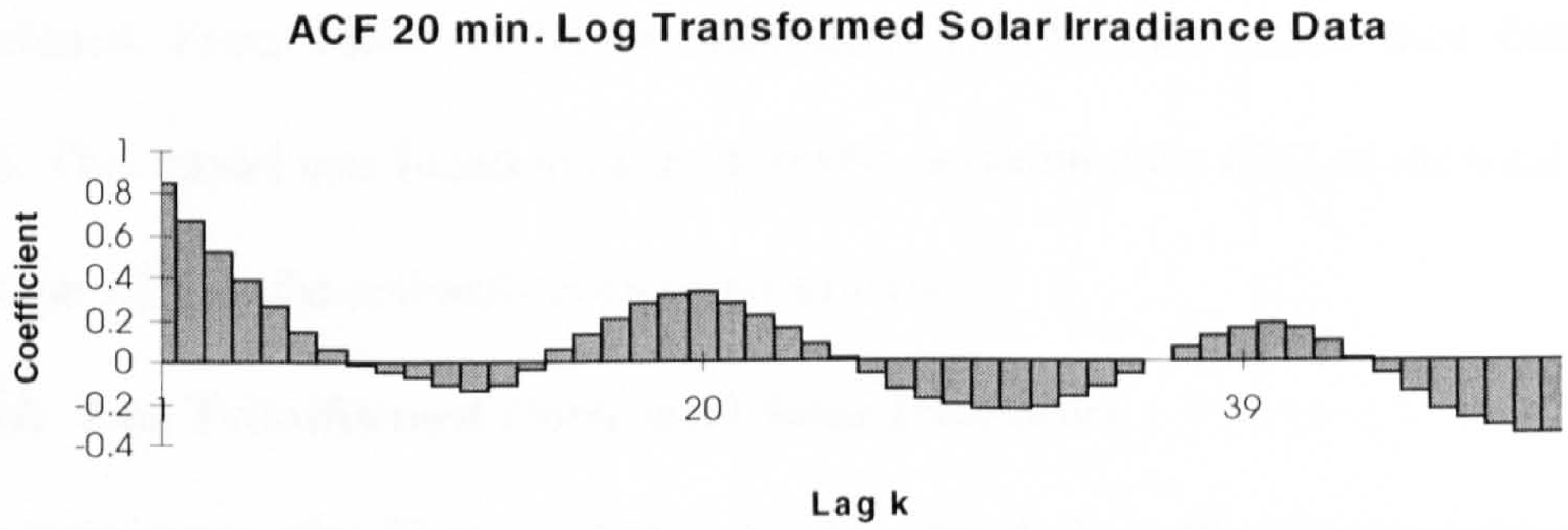


Figure 4.2.4 Log transformed Vertical Solar Irradiance - 20 minute averages, DEC93_20

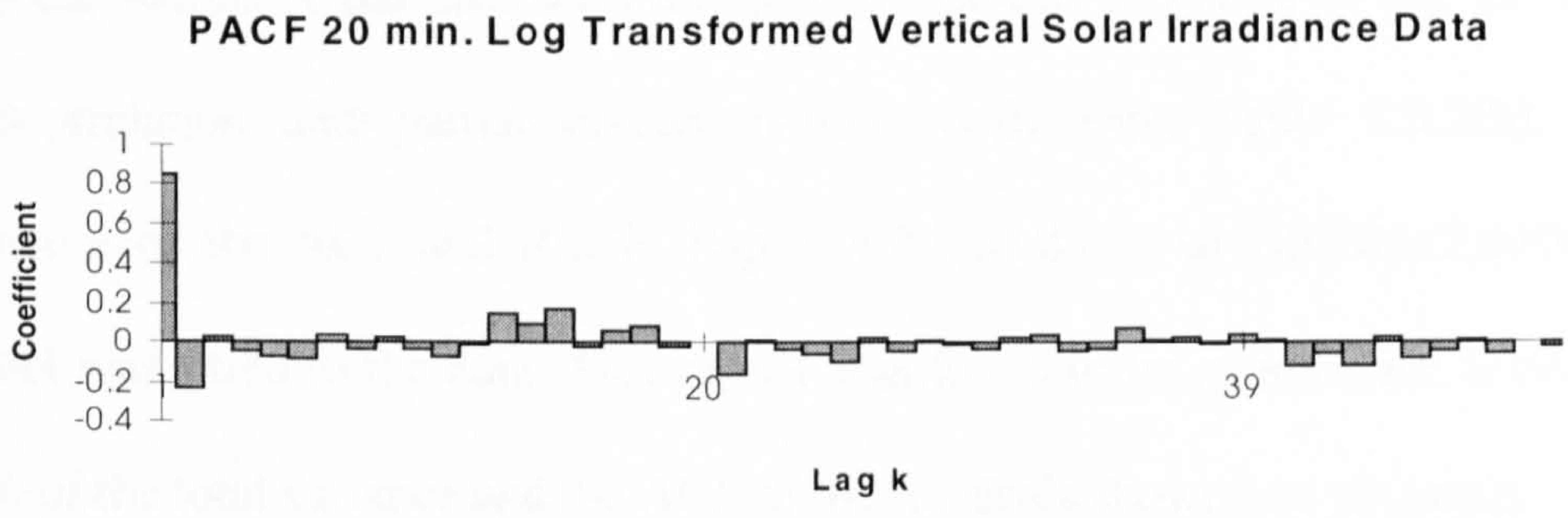
a)



b)



c)



4.3. December 1993 - Thirty minute averages

This data set, known as DEC93_30, contains 30 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 17th and 31st December 1993.

4.3.1. Horizontal Solar Irradiance

The time series plot, Figure 4.3.1(a), displays the daily cyclic nature of the data with 13 observations per day. The ACF of the data, Figure 4.3.1(b) also emphasises the periodic nature of the data with damped oscillations repeating at lag 13. From the autocorrelation and partial autocorrelation coefficients, Table 4.3.1(b), and the structure of the ACF and PACF, Figure 4.3.1(b) &(c), an ARIMA(2,0,0)(1,0,0)13 model was fitted to the data. This model was found to be adequate, accounted for 68% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.3.1(b) an ARIMA(1,1,0)(1,0,0)13 model was fitted to the data. This model was found to be appropriate, accounted for 62% of the total variance and the ACF of the residuals showed no structure.

4.3.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.3.2(a), displays the daily cyclic nature of the data with 13 observations per day. The ACF of the data, Figure 4.3.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 13. From the autocorrelation and partial autocorrelation coefficients, Table 4.3.2(b), and the structure of the ACF and PACF, Figure 4.3.2(b) &(c), an ARIMA(2,0,0)(1,0,0)13 model was fitted to the data. This model was found to be appropriate, accounted for 71% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.3.2(b) an ARIMA(1,1,0)(1,0,0)13 model was fitted to thedata. The backforecasts did not die out rapidly and this model was rejected.

4.3.3. Vertical Solar Irradiance

The time series plot, Figure 4.3.3(a), displays the daily cyclic nature of the data with 13 observations per day. The ACF of the data also emphasises the periodic nature of the data with damped oscillations repeating at lag 13. From the autocorrelation and partial autocorrelation coefficients, Table 4.3.3(b), and the structure of the ACF and PACF, Figure 4.3.3(b) & (c), an ARIMA(2,0,0)(1,0,0)13 model was fitted to the data. This model was found to be appropriate, accounted for 63% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.3.3(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

4.3.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.3.4(a), displays the daily cyclic nature of the data with 13 observations per day. The ACF of the data, Figure 4.3.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 13. From the autocorrelation and partial autocorrelation coefficients, Table 4.3.4(b), and the structure of the ACF and PACF, Figure 4.3.4(b) & (c), an ARIMA(2,0,0)(1,0,0)13 model was fitted to the data. This model was found to be appropriate, accounted for 65% of the total variance of the data and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.3.4(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

Table 4.3.1 Summary Information for Horizontal Solar Irradiance - 30 minute averages (datafile DEC93_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0693	0.0506	0.0032	0.1958

b)

$2/\sqrt{195} = 0.143$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.793	0.793	0.193	0.193
2	0.510	-0.321	-0.023	-0.063
3	0.241	-0.116	0.006	0.025
4	-0.020	-0.214	-0.102	-0.114
13	0.449	-0.030	0.264	-0.010

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,0,0)(1,0,0)13	AR1	0.9796	0.0712	13.76	0.1534	0.000803	68
	AR2	-0.2649	0.0707	-3.74			
	SAR14	0.2314	0.0733	3.16			
	CONST	0.0153	0.00203	7.56			
ARIMA(1,1,0)(1,0,0)13	AR1	0.1152	0.0729	1.58	0.1832	0.000955	62
	SAR13	0.2484	0.0727	3.42			
ARIMA(1,0,0)(1,0,0)13	AR1	0.7813	0.0466	16.78	0.16338	0.000851	66
	SAR13	0.3141	0.0708	4.58			
	CONST	0.0102	0.0021	4.87			

Table 4.3.2 Summary Information for Log Transformed Horizontal Solar Irradiance - 30 minute averages (datafile DEC93_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0071	0.9157	-5.7551	-1.6305

b)

$2/\sqrt{195} = 0.143$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.743	0.743	0.144	0.144
2	0.421	-0.293	-0.091	-0.114
3	0.149	-0.093	-0.020	0.012
4	-0.106	-0.222	-0.146	-0.160
13	0.607	0.142	0.543	0.328

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)(1,0,0)13	AR1	0.8350	0.0720	11.59	45.184	0.2366	71
	AR2	-0.1655	0.0719	-2.30			
	SAR14	0.5838	0.0613	9.52			
	CONST	-0.4105	0.0348	-11.77			
ARIMA(1,0,0)(1,0,0)13	AR1	0.7122	0.0507	14.05	46.3921	0.2416	71
	SAR13	0.6153	0.0592	10.40			
	CONST	-0.3308	0.0352	-9.39			

Table 4.3.3 Summary Information for Vertical Solar Irradiance - 30 minute averages (datafile DEC93_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1712	0.2122	0.0019	0.7270

b)

$2/\sqrt{195} = 0.143$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.792	0.792	0.049	0.049
2	0.564	-0.171	-0.088	-0.090
3	0.375	-0.039	-0.019	-0.010
4	0.196	-0.112	-0.068	-0.075
13	0.225	-0.126	0.050	-0.107

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,0,0)(1,0,0)13	AR1	0.9188	0.0725	12.67	3.133	0.0164	63
	AR2	-0.1625	0.0721	-2.25			
	SAR14	0.0469	0.0755	0.62			
	CONST	0.0393	0.00918	4.29			
ARIMA(1,0,0)(1,0,0)13	AR1	0.7883	0.0447	17.64	3.21442	0.01674	63
	SAR13	0.0800	0.0747	1.07			
	CONST	0.0327	0.0093	3.53			

Table 4.3.4 Summary Information for Log Transformed Vertical Solar Irradiance - 30 minute averages (datafile DEC93_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.7510	1.5510	-6.2490	-0.3190

b)

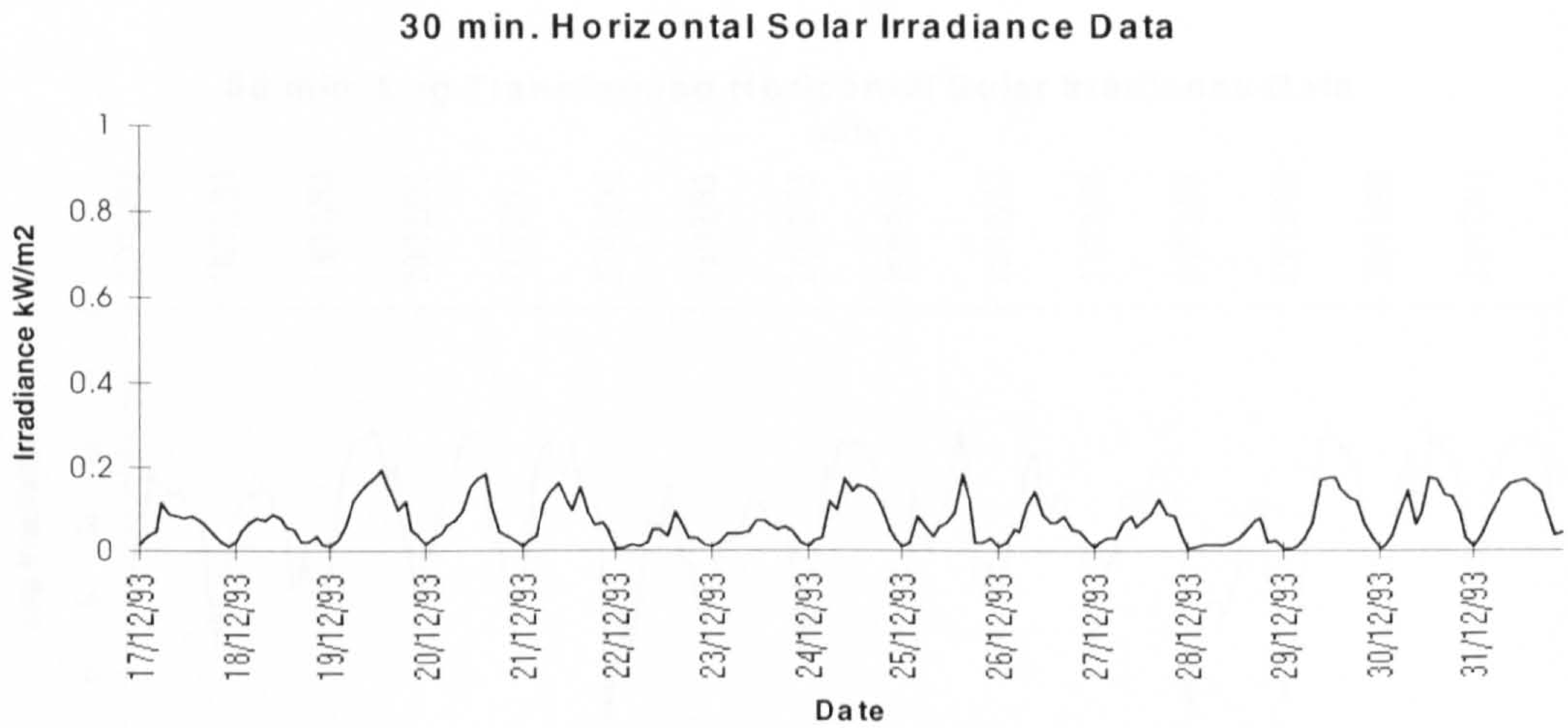
$2/\sqrt{195} = 0.143$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.775	0.775	0.054	0.054
2	0.529	-0.178	-0.124	-0.127
3	0.337	-0.022	-0.014	0.001
4	0.156	-0.128	-0.150	-0.168
13	0.328	-0.007	0.297	0.161

c)

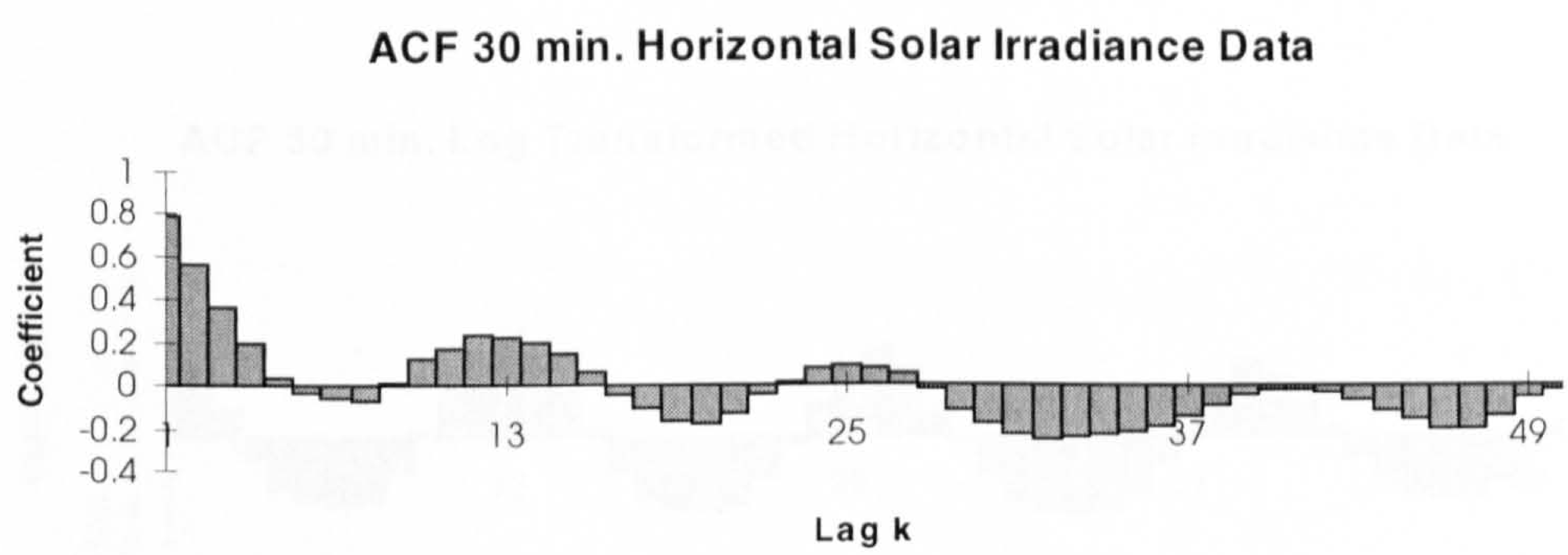
model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,0,0)(1,0,0)13	AR1	0.8946	0.0724	12.36	160.628	0.841	65
	AR2	-0.1576	0.0722	-2.18			
	SAR14	0.3218	0.0712	4.52			
	CONST	-0.4858	0.0657	-7.39			
ARIMA(1,0,0)(1,0,0)13	AR1	0.7725	0.0460	16.80	164.591	0.857	64
	SAR13	0.3365	0.0701	4.80			
	CONST	-0.4121	0.0664	-6.21			

Figure 4.3.1 Horizontal Solar Irradiance - 30 minute averages, DEC93_30

a)



b)



c)

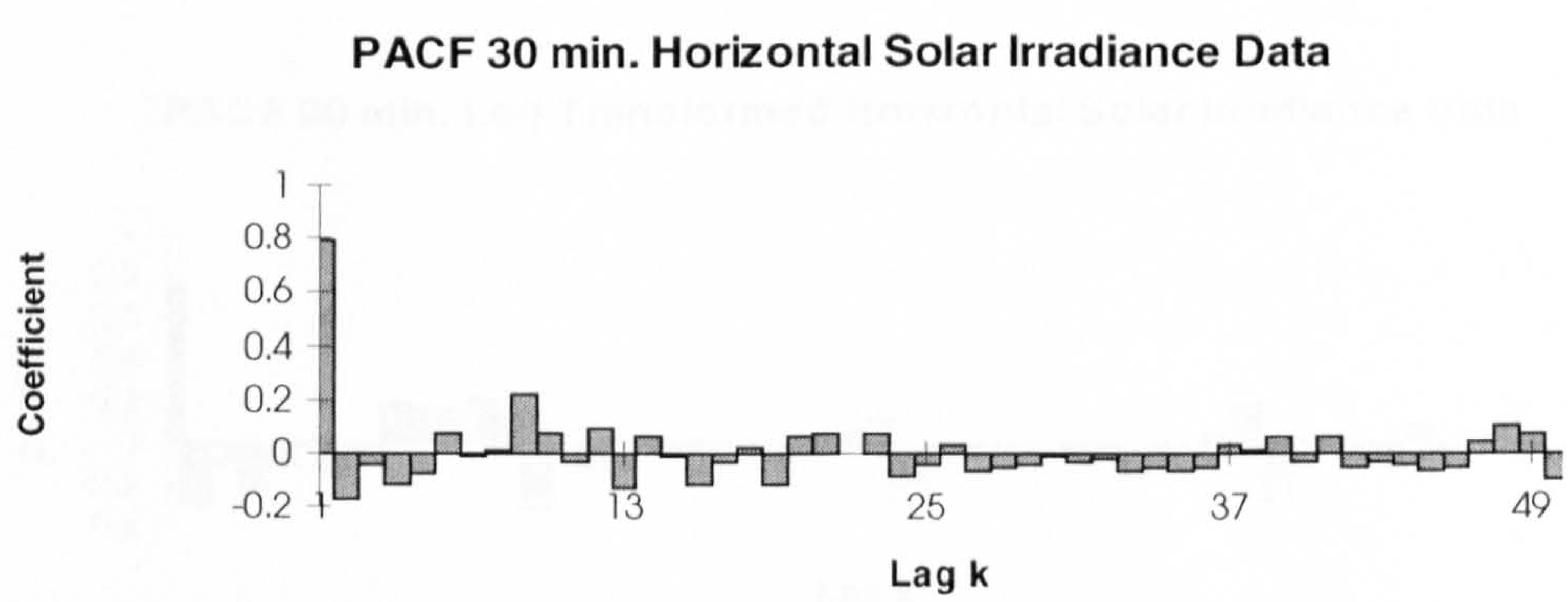
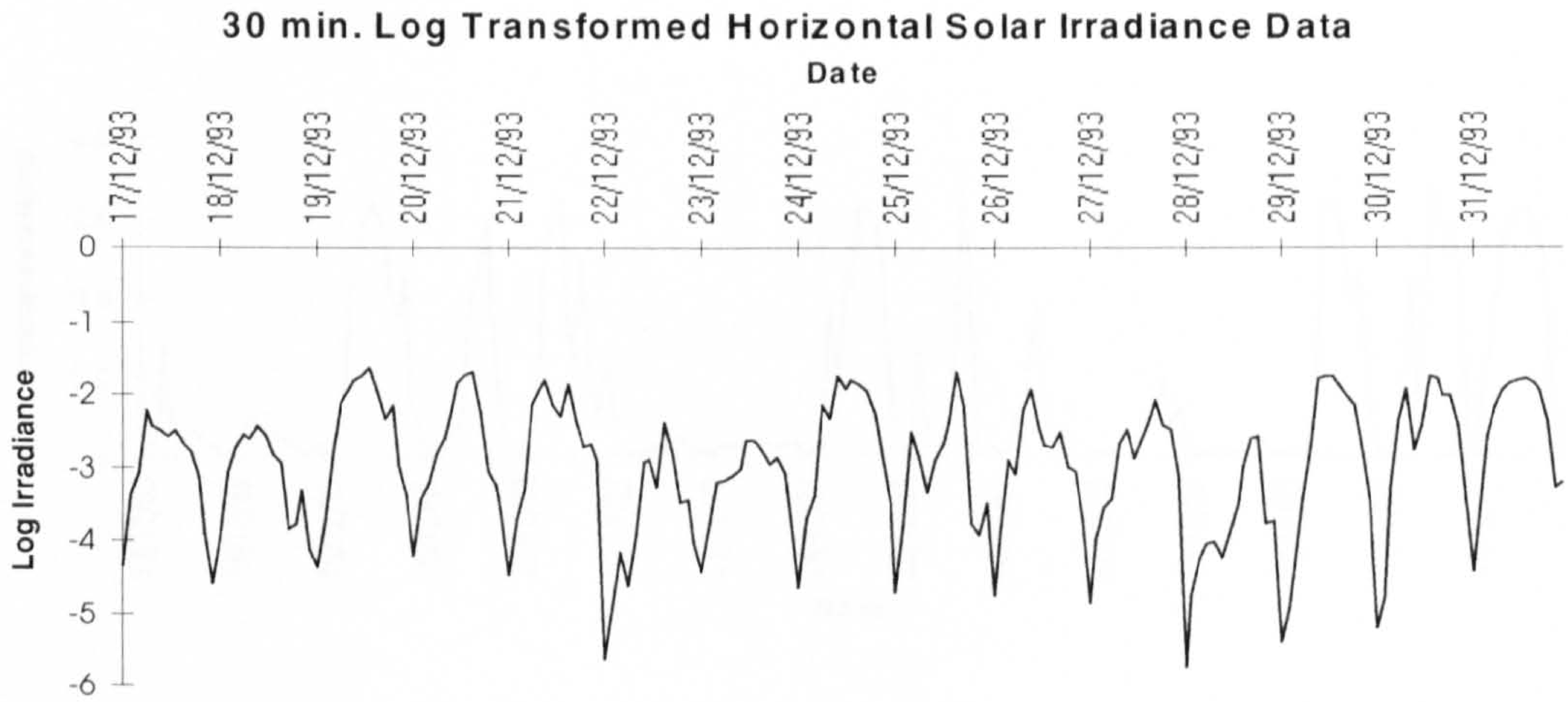
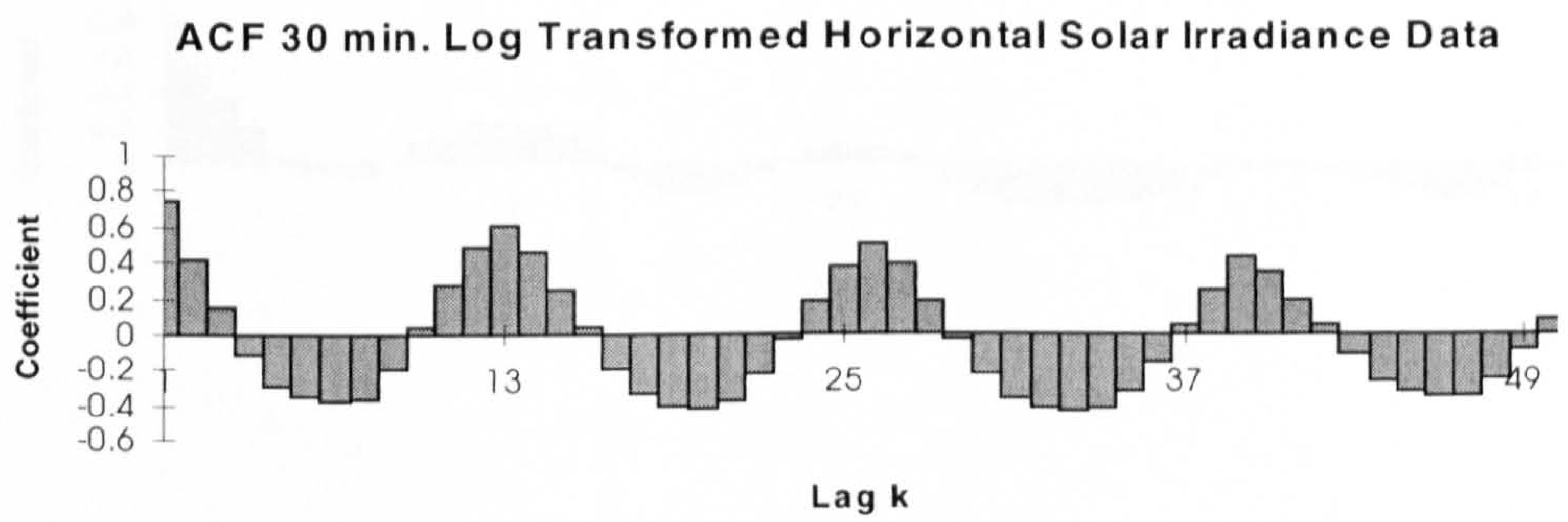


Figure 4.3.2 Log transformed Horizontal Solar Irradiance - 30 minute averages, DEC93_30

a)



b)



c)

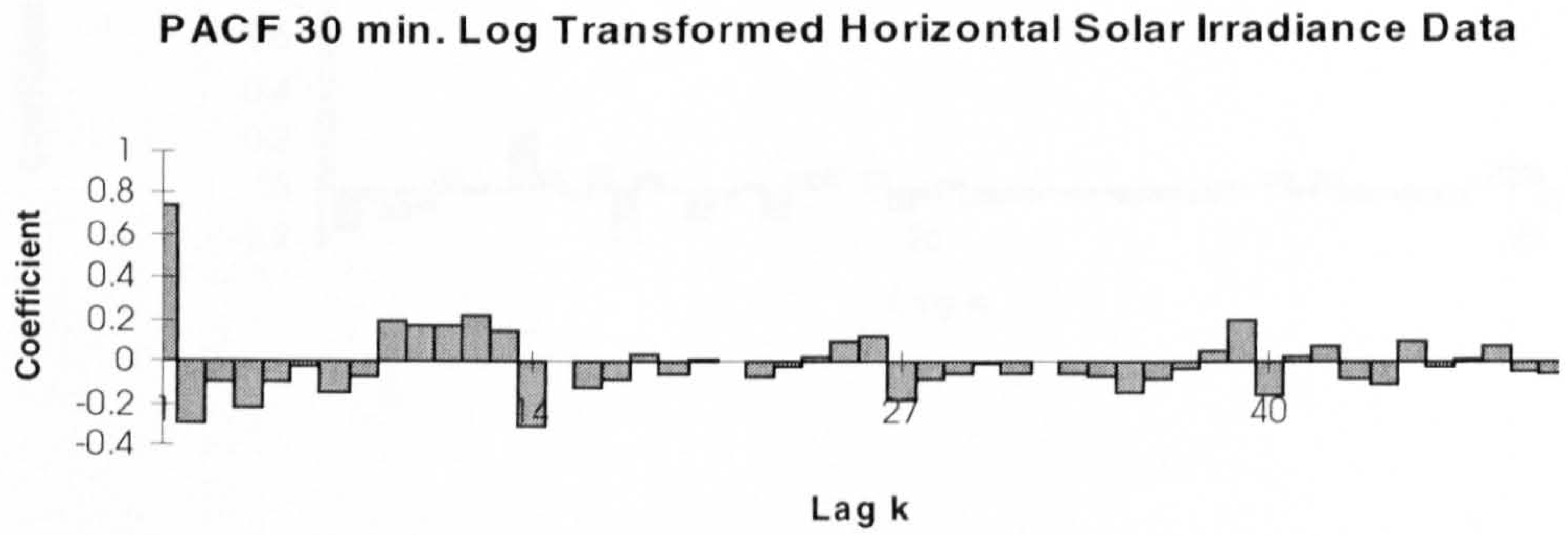
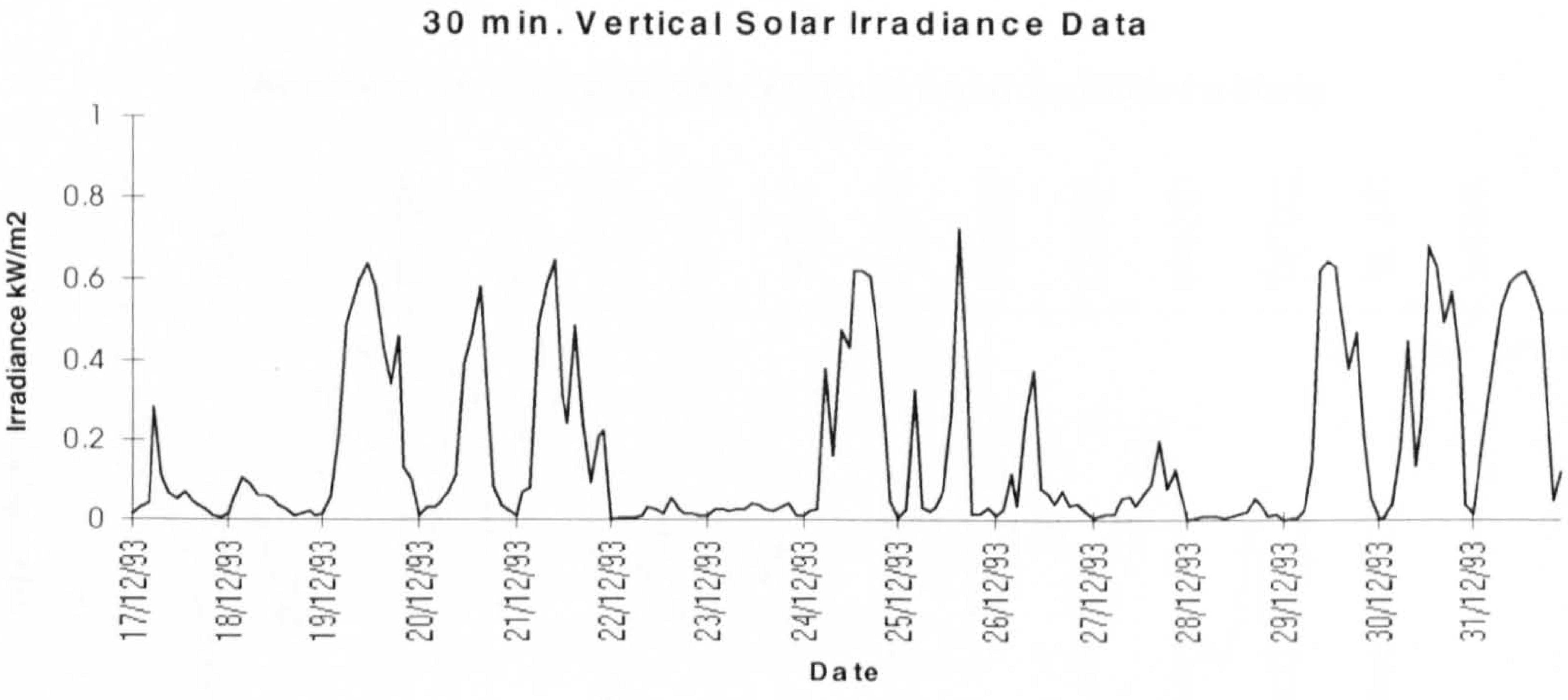
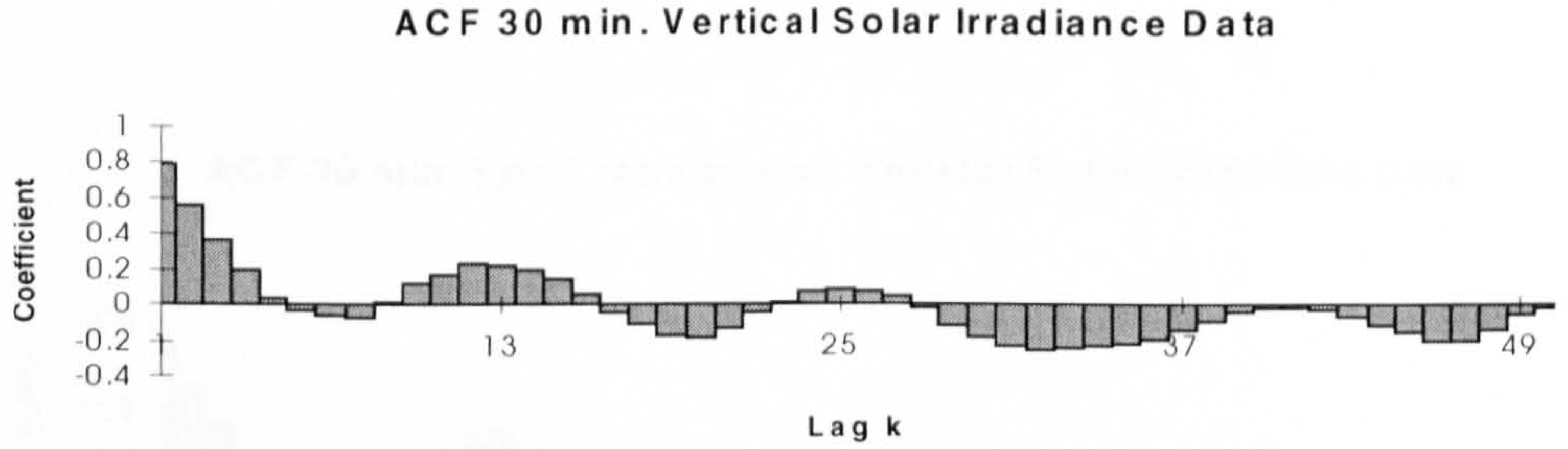


Figure 4.3.3 Vertical Solar Irradiance - 30 minute averages, DEC93_30

a)



b)



c)

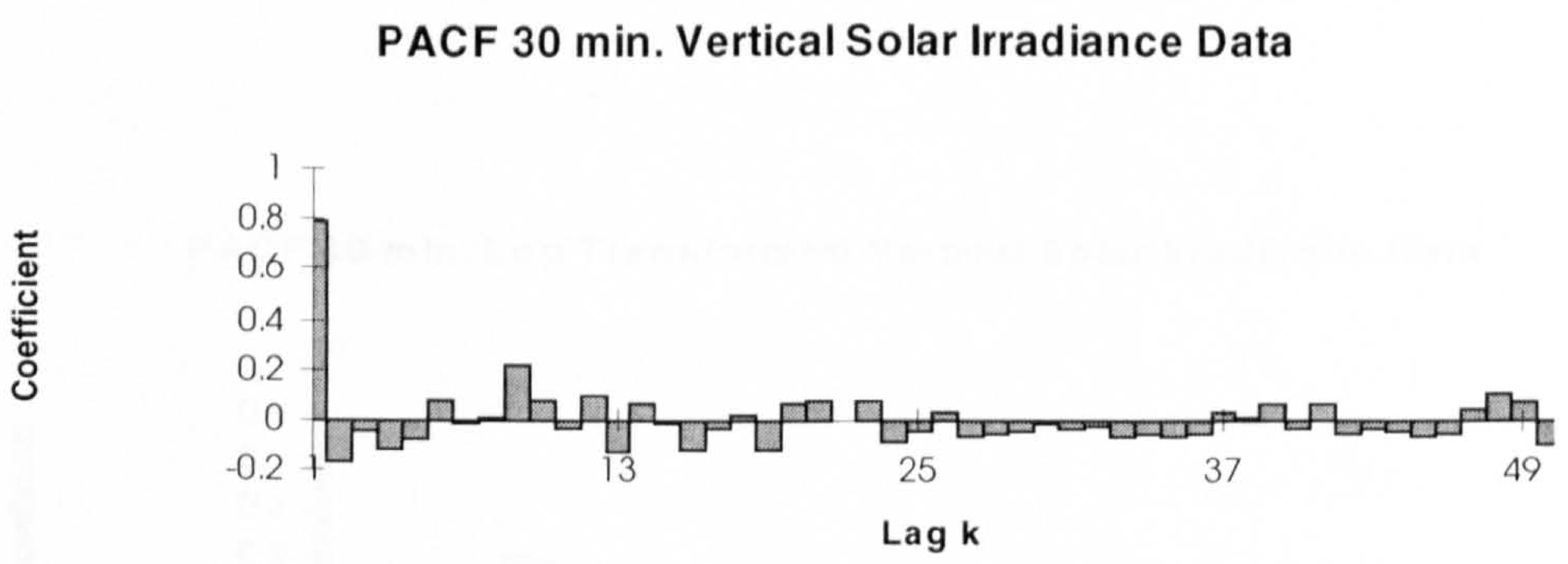
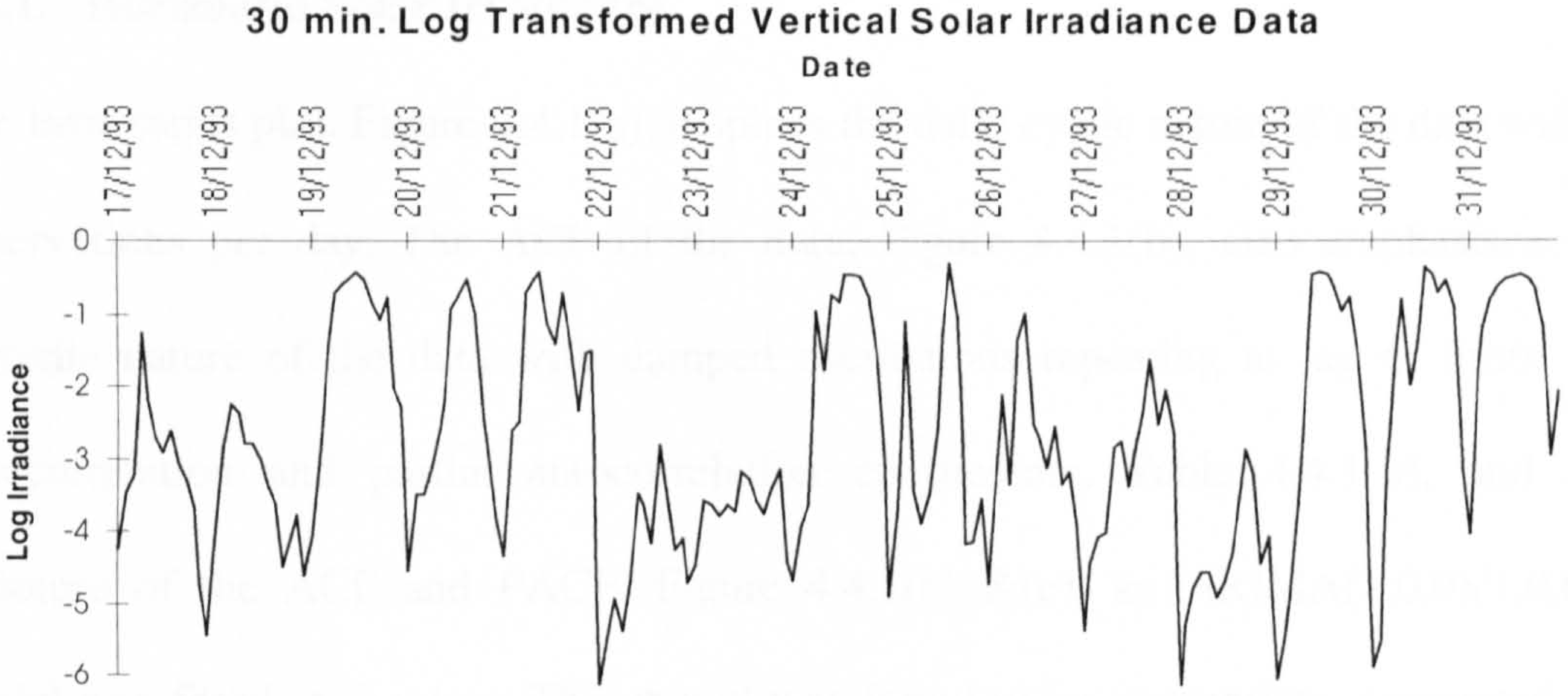
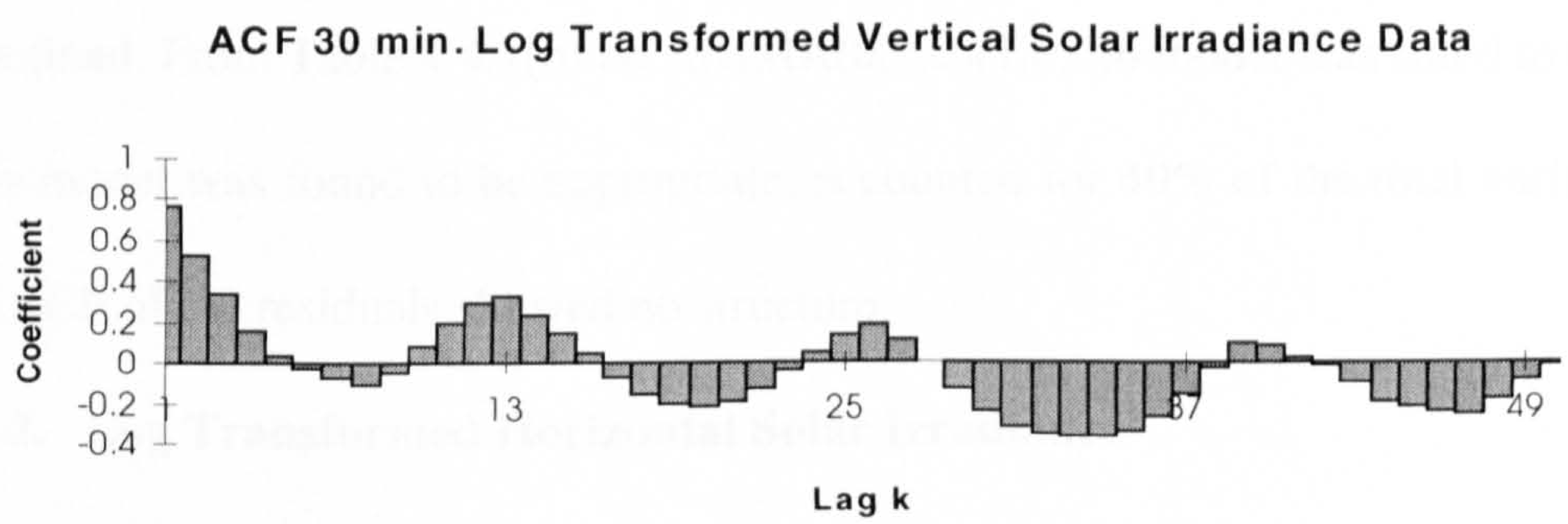


Figure 4.3.4 Log transformed Vertical Solar Irradiance - 30 minute averages, DEC93_30

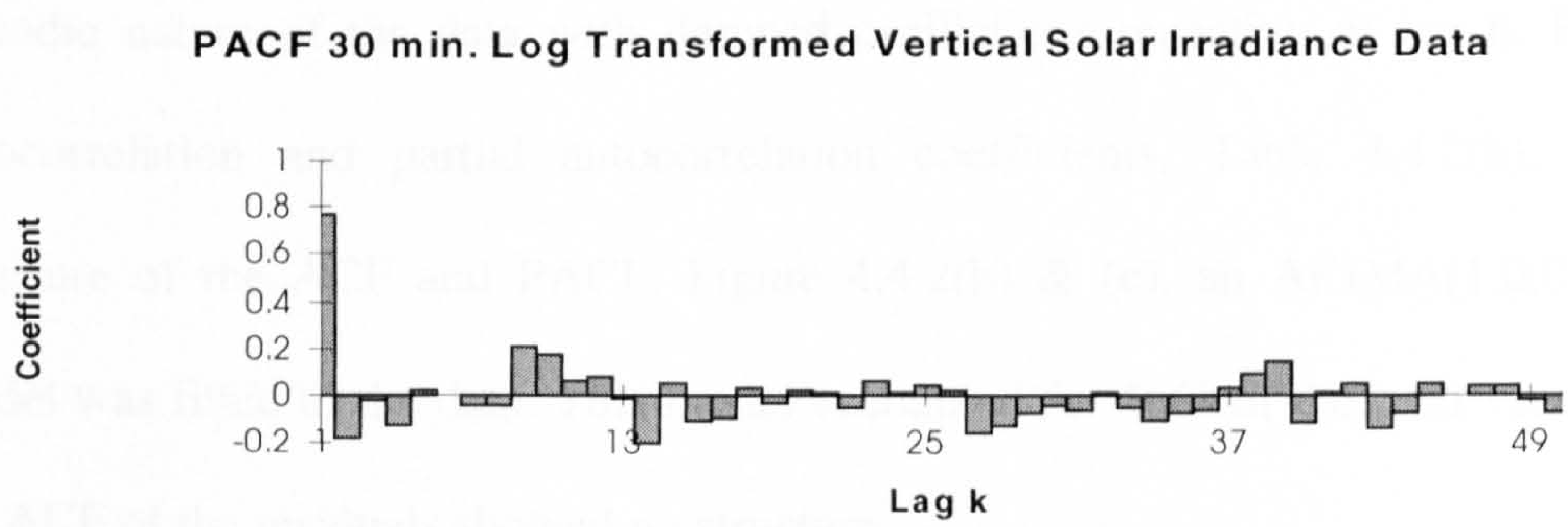
a)



b)



c)



4.4. December 1993 - Sixty minute averages

This data set, known as DEC93_60, contains 60 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 17th and 31st December 1993.

4.4.1. Horizontal Solar Irradiance

The time series plot, Figure 4.4.1(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.4.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.4.1(b), and the structure of the ACF and PACF, Figure 4.4.1(b) &(c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model was found to be appropriate, accounted for 50% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.4.1(b) an ARIMA(0,1,0)(1,0,0)6 model was fitted to the data. This model was found to be appropriate, accounted for 40% of the total variance and the ACF of the residuals showed no structure.

4.4.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.4.2(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.4.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.4.2(b), and the structure of the ACF and PACF, Figure 4.4.2(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 56% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.4.2(b) an ARIMA(0,1,0)(1,0,0)6 model was fitted to the data. This model accounted for 43% of the total variance and the ACF of the residuals showed no structure.

4.4.3. Vertical Solar Irradiance

The time series plot, Figure 4.4.3(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.4.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.4.3(b), and the structure of the ACF and PACF, Figure 4.4.3(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 42% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.4.3(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

4.4.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.4.4(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.4.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.4.4(b), and the structure of the ACF and PACF, Figure 4.4.4(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 39% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.4.4(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

Table 4.4.1 Summary Information for Horizontal Solar Irradiance - 60 minute averages (datafile DEC93_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0727	0.0482	0.0052	0.1855

b)

$2/\sqrt{90} = 0.211$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.524	0.524	0.120	0.120
2	-0.049	-0.445	-0.329	-0.349
3	-0.309	-0.067	-0.424	-0.380
4	-0.174	0.116	-0.277	-0.423
6	0.454	0.144	0.491	0.127

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)6	AR1	0.5794	0.0893	6.08	0.10797	0.001241	46
	SAR6	0.5472	0.0966	5.67			
	CONST	0.0139	0.0037	3.76			
ARIMA(2,0,0)(1,0,0)6	AR1	0.7166	0.1041	6.89	0.10057	0.001169	50
	AR2	-0.2971	0.1064	-2.79			
	SAR6	0.4290	0.1064	4.03			
	CONST	0.02405	0.0036	6.66			
ARIMA(0,1,0)(1,0,0)6	SAR6	0.5560	0.0967	5.75	0.14103	0.001603	30

Table 4.4.2 Summary Information for Log Transformed Horizontal Solar Irradiance - 60 minute averages (datafile DEC93_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.9165	0.8692	-5.2559	-1.6845

b)

$2/\sqrt{90} = 0.211$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.384	0.384	-0.076	-0.076
2	-0.126	-0.321	-0.289	-0.297
3	-0.282	-0.124	-0.173	-0.247
4	-0.227	-0.107	-0.300	-0.512
6	0.613	0.462	0.699	0.353

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)6	AR1	0.5213	0.0916	5.69	28.6783	0.3296	56
	SAR6	0.7411	0.0772	9.60			
	CONST	-0.3562	0.0606	-5.88			
ARIMA(0,1,0)(1,0,0)6	SAR6	0.7662	0.0740	10.36	37.6348	0.4277	43

Table 4.4.3 Summary Information for Vertical Solar Irradiance - 60 minute averages (datafile DEC93_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1811	0.2047	0.0030	0.6421

b)

$2/\sqrt{90} = 0.211$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.624	0.624	0.024	0.024
2	0.235	-0.252	-0.247	-0.248
3	0.027	0.002	-0.297	-0.302
4	0.040	0.134	-0.153	-0.256
6	0.237	0.048	0.229	0.023

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.6258	0.0838	7.46	2.1153	0.02431	42
	SAR6	0.2747	0.1116	2.46			
	CONST	0.04854	0.01645	2.95			

Table 4.4.4 Summary Information for Log Transformed Vertical Solar Irradiance - 60 minute averages (datafile DEC93_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.5990	1.5110	-5.7980	-0.4430

b)

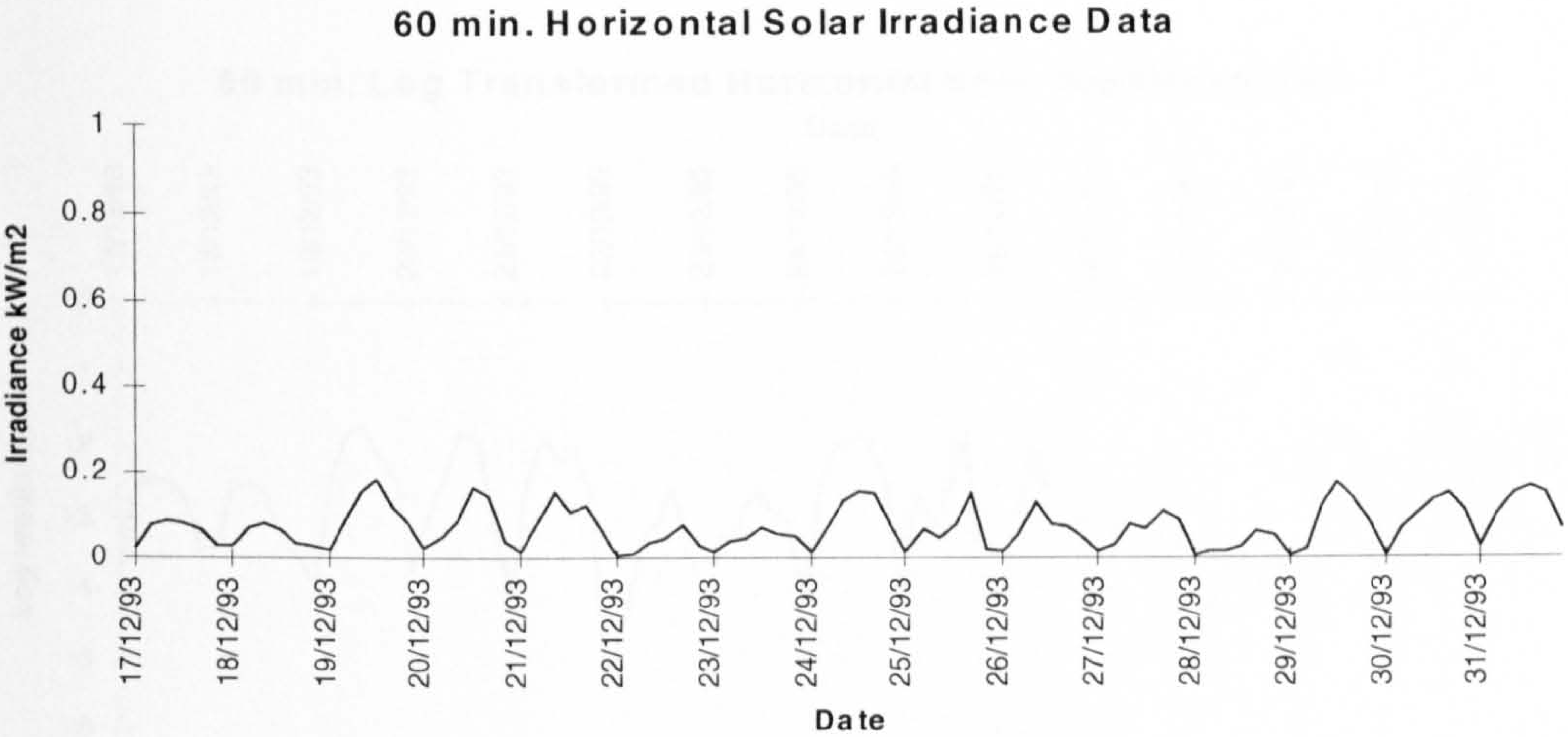
$2/\sqrt{90} = 0.211$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.537	0.537	-0.132	-0.132
2	0.201	-0.123	-0.207	-0.228
3	0.050	-0.008	-0.102	-0.177
4	-0.010	-0.018	-0.250	-0.384
6	0.322	0.185	0.400	0.185

c)

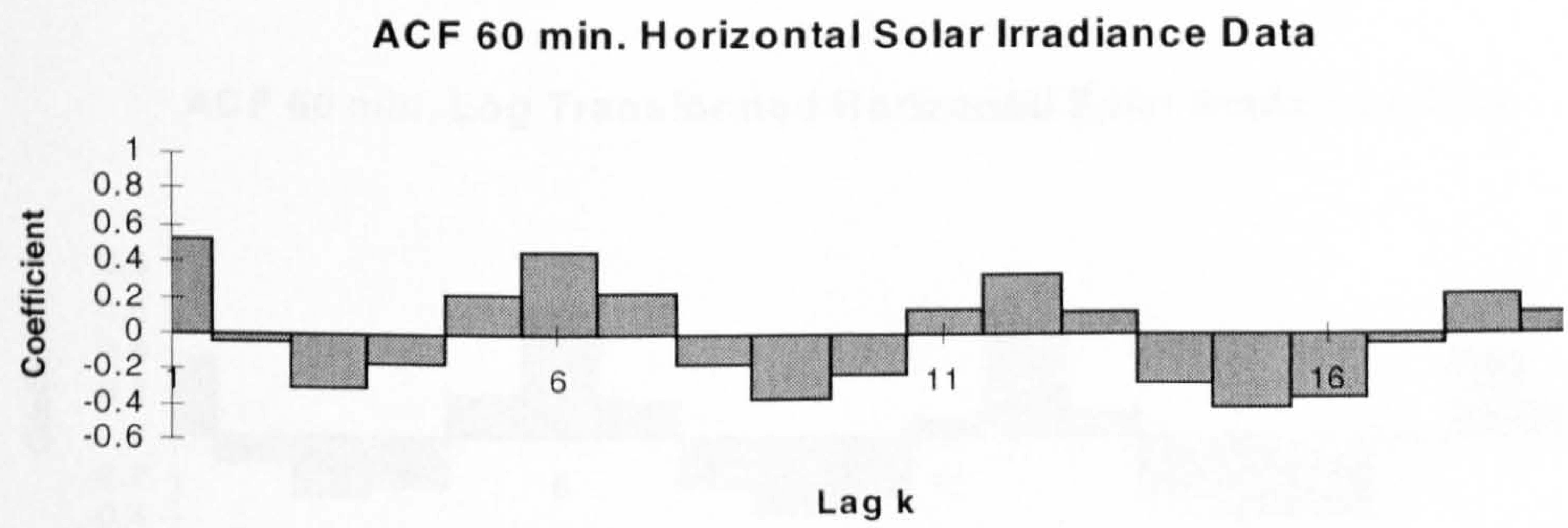
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.5732	0.0877	6.54	120.226	1.382	39
	SAR6	0.4127	0.0998	4.14			
	CONST	-0.6445	0.1240	-5.20			

Figure 4.4.1 Horizontal Solar Irradiance - 60 minute averages, DEC93_60

a)



b)



c)

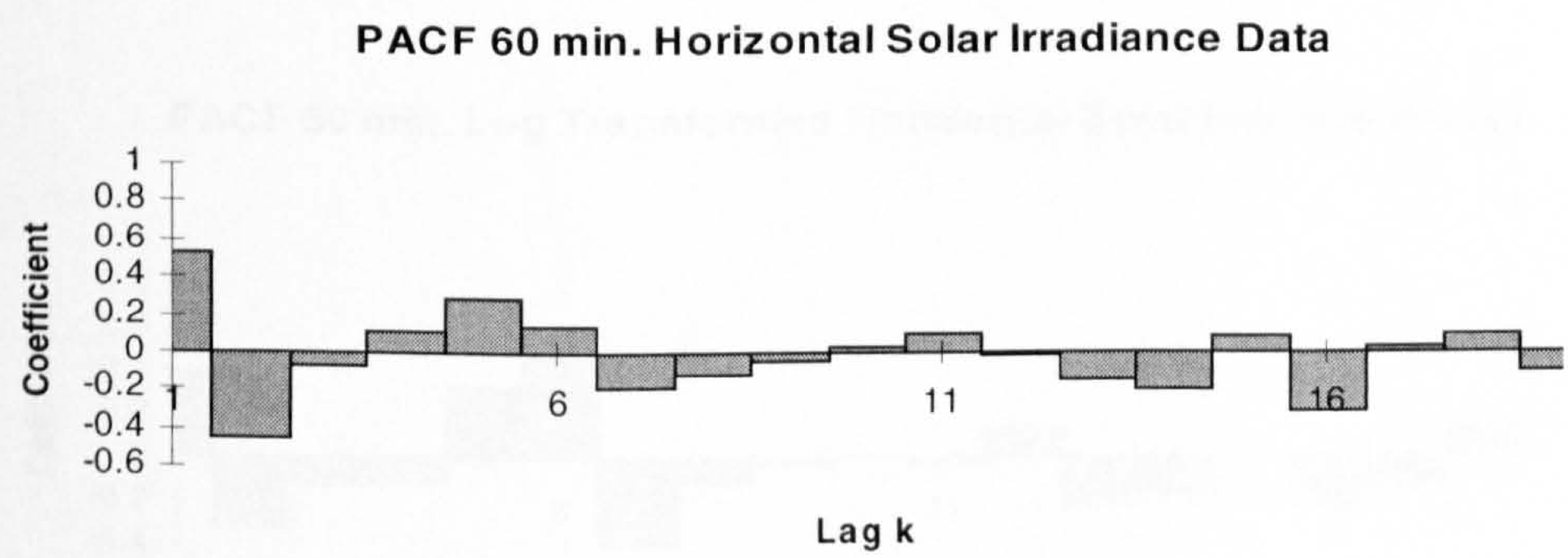
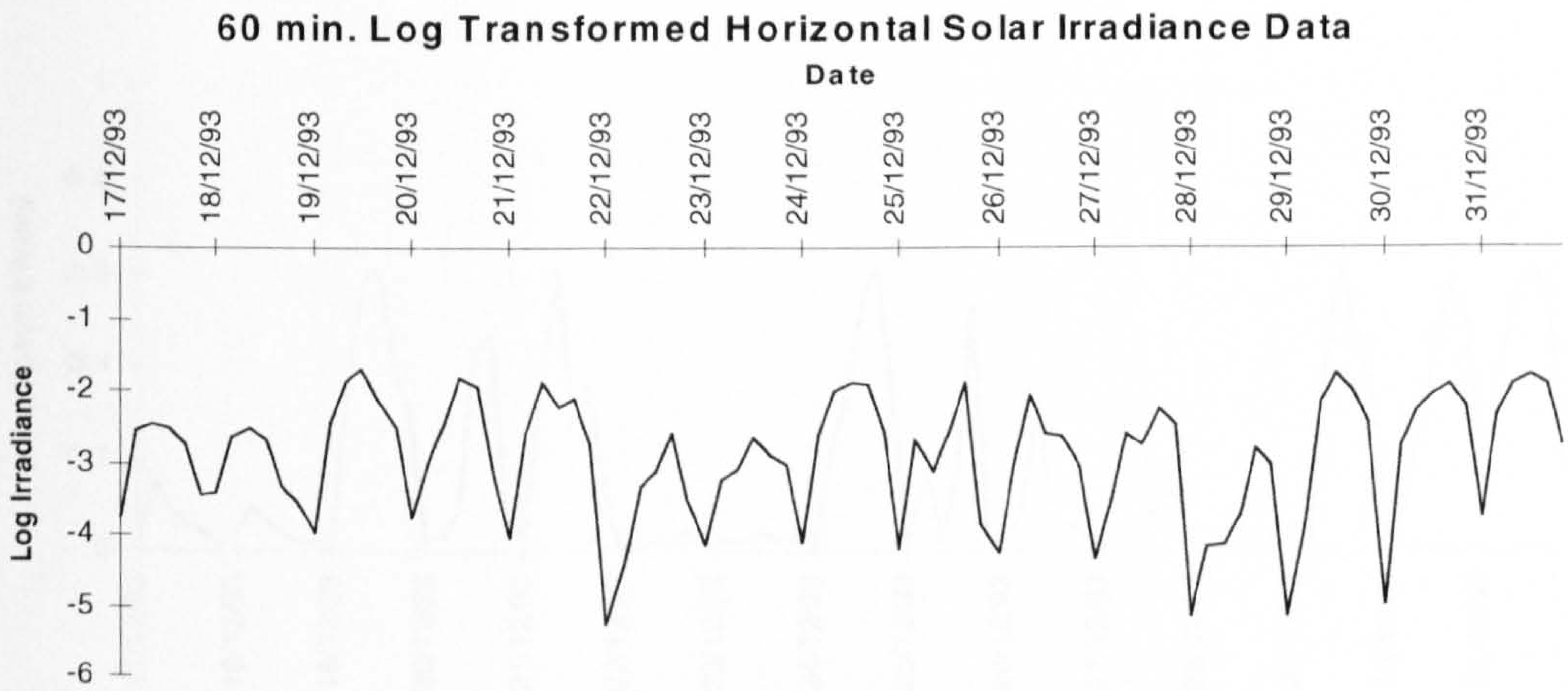
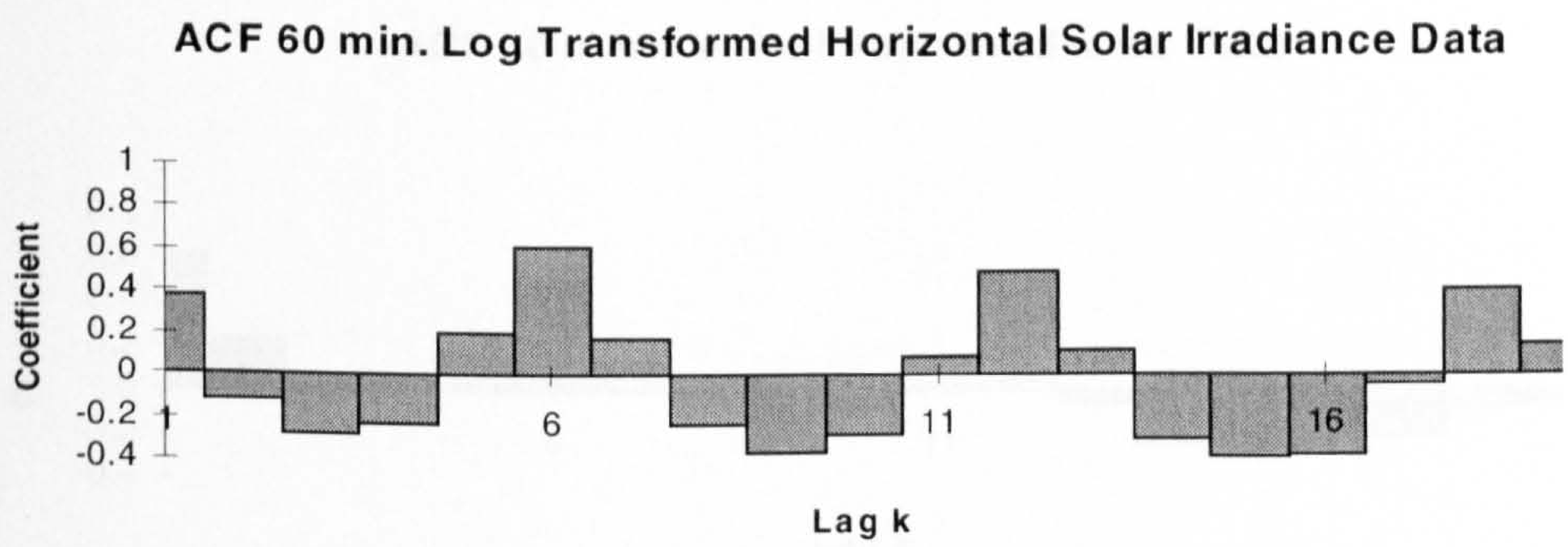


Figure 4.4.2 Log transformed Horizontal Solar Irradiance - 60 minute averages, DEC93_60

a)



b)



c)

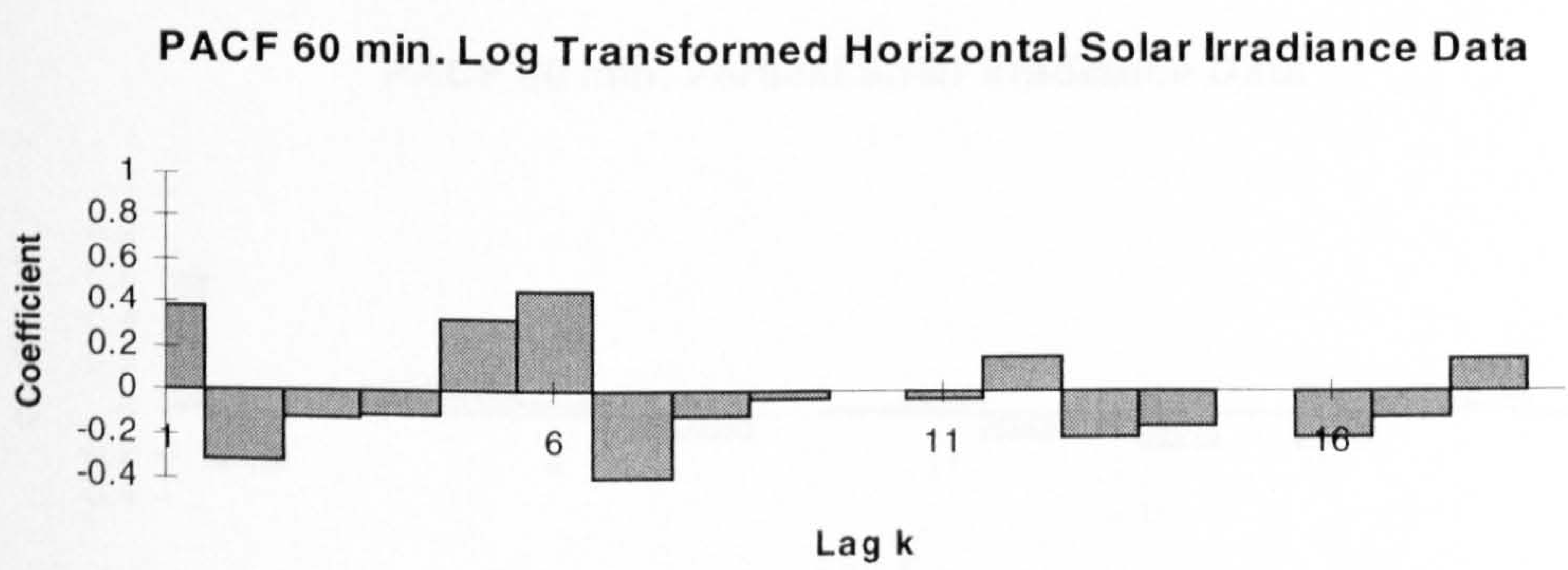
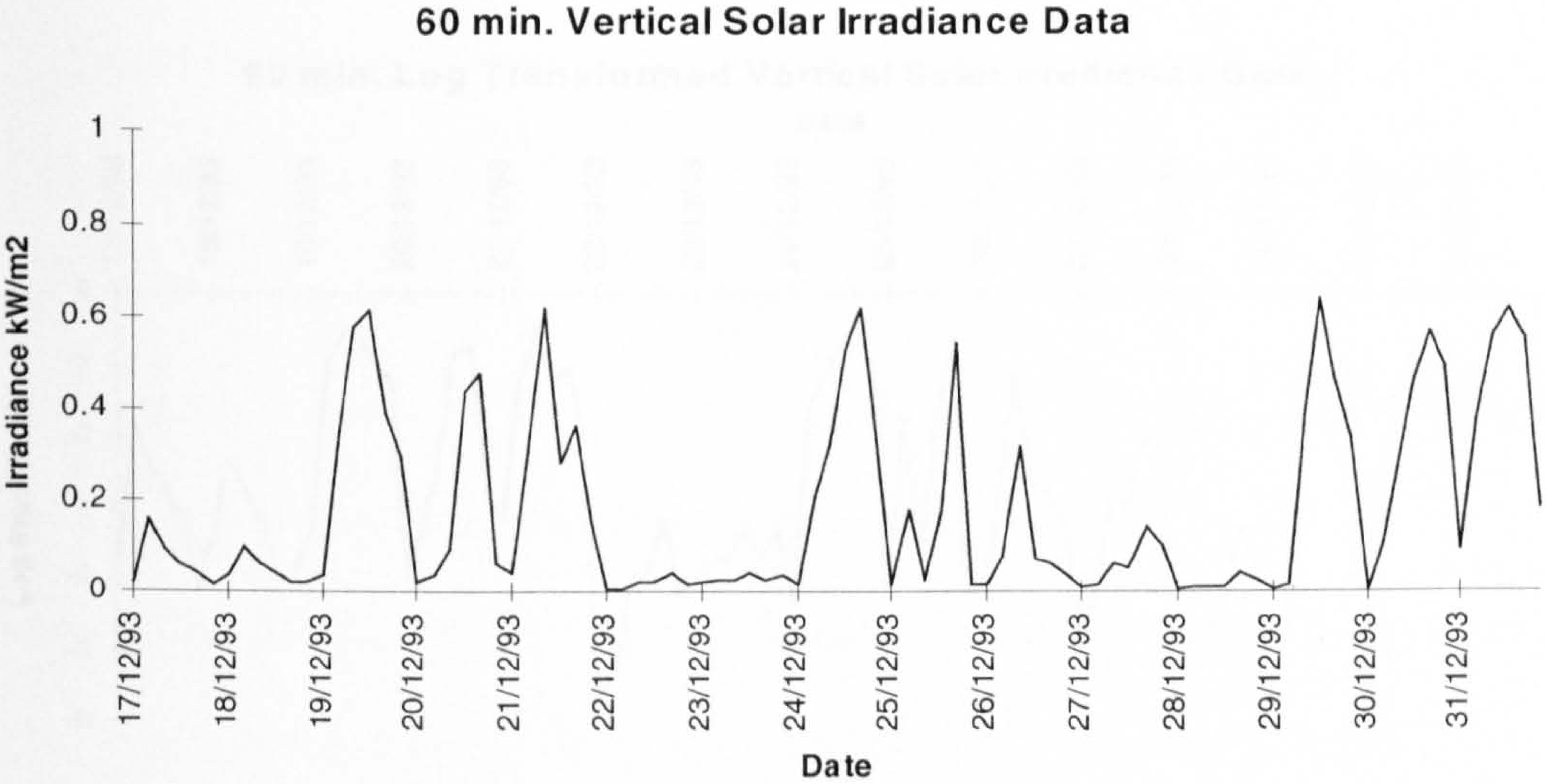
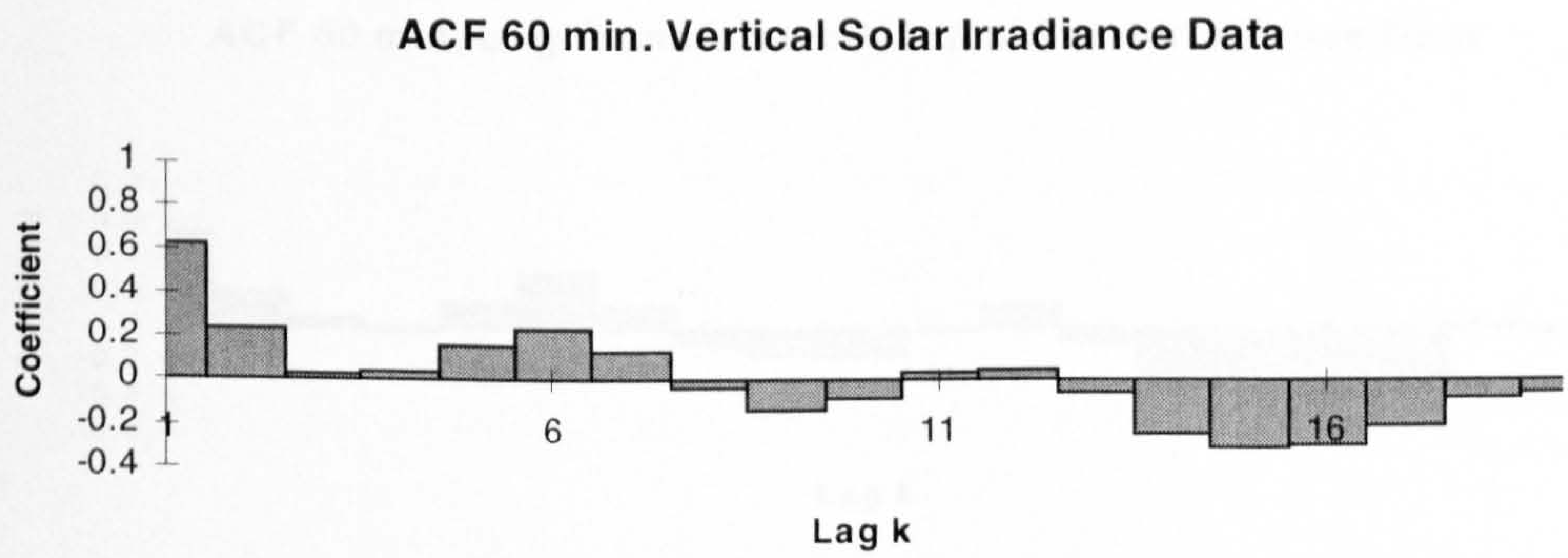


Figure 4.4.3 Vertical Solar Irradiance - 60 minute averages, DEC93_60

a)



b)



c)

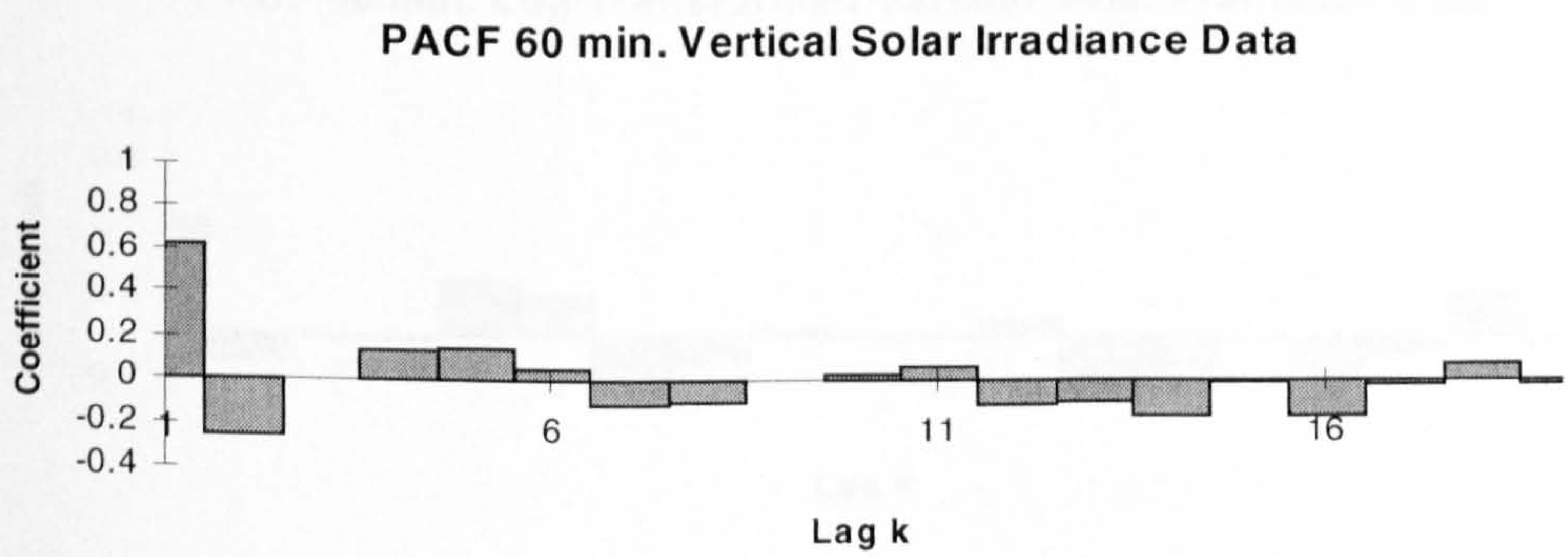
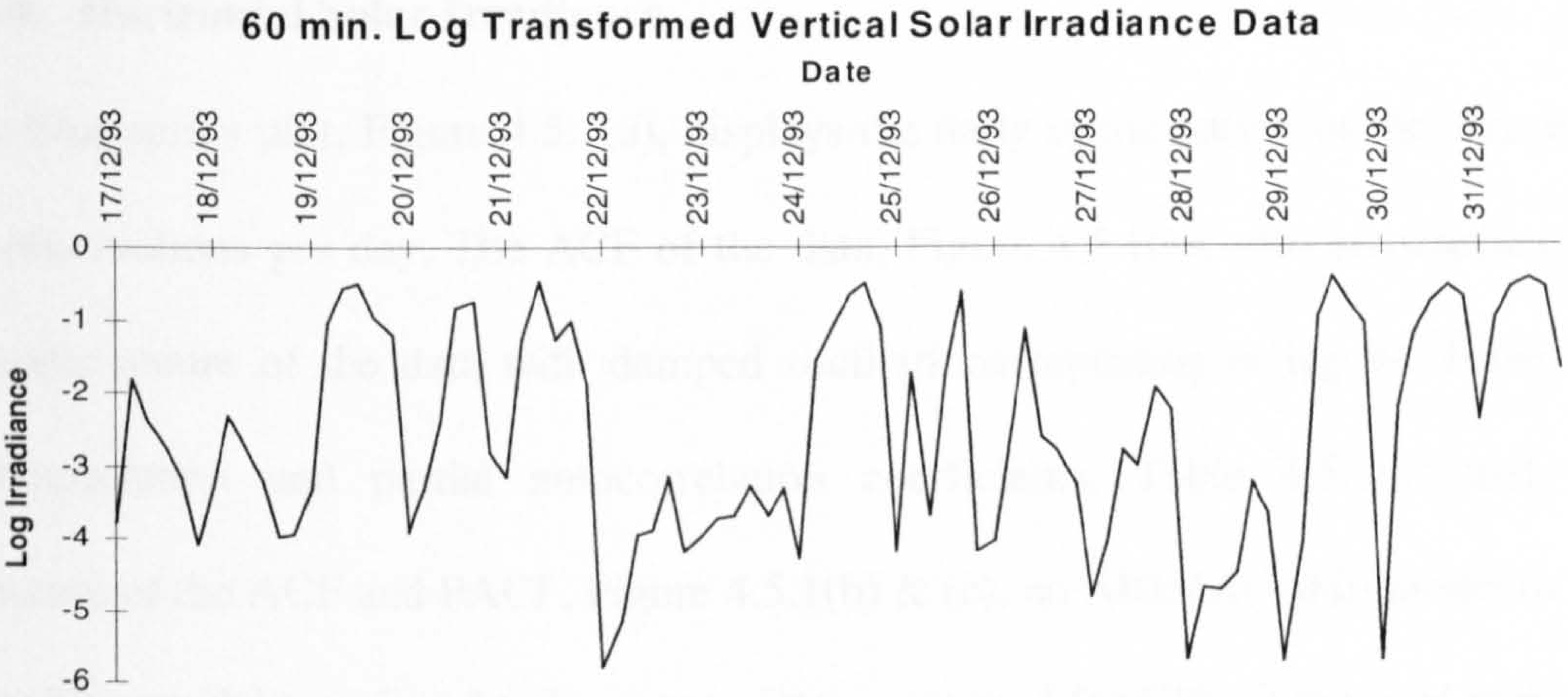
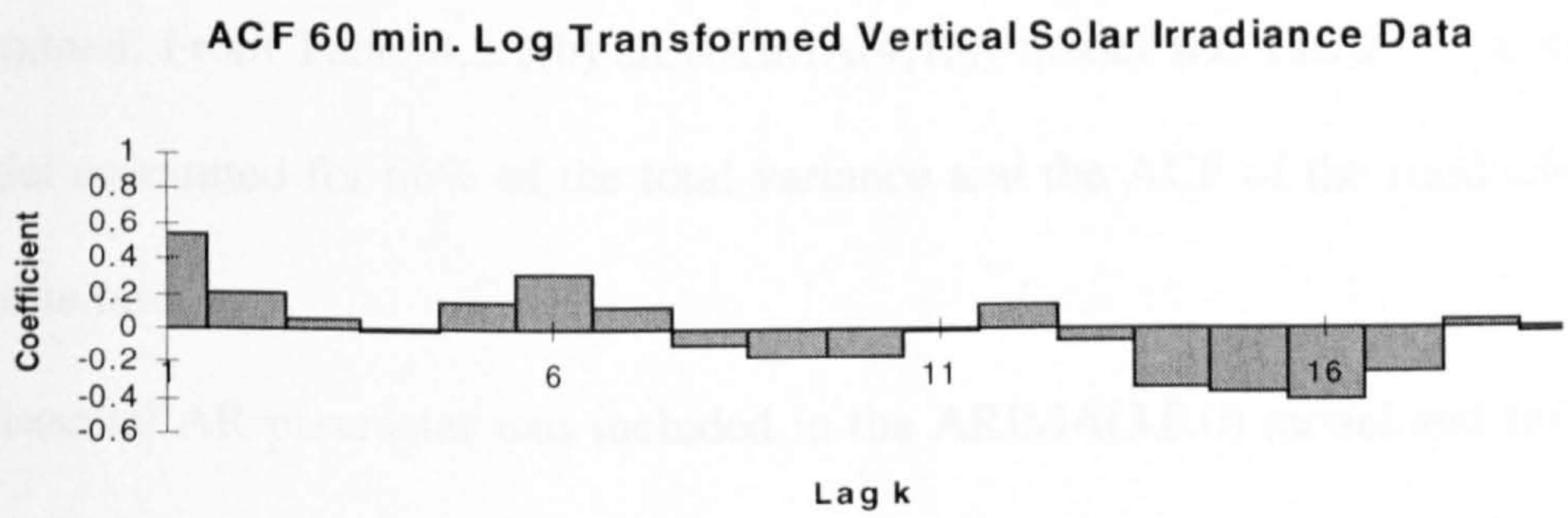


Figure 4.4.4 Log transformed Vertical Solar Irradiance - 60 minute averages, DEC93_60

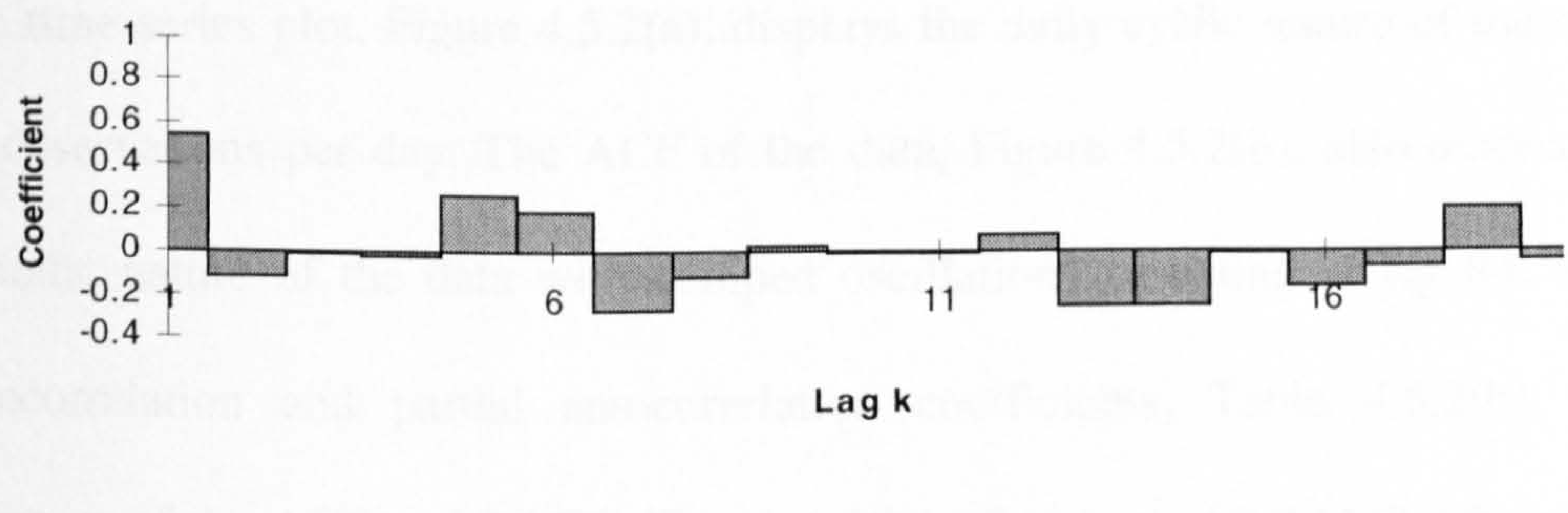
a)



b)



c)



4.5. June 1994 (1st-9th) - Ten minute averages

This data set, known as JUN94_10, contains 10 minute averaged Horizontal and Vertical Solar Irradiance data recorded between 1st and 9th June 1994.

4.5.1. Horizontal Solar Irradiance

The time series plot, Figure 4.5.1(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.5.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.5.1(b) and the structure of the ACF and PACF, Figure 4.5.1(b) & (c), an ARIMA(3,0,0) model to the data. This model was found to be appropriate, accounted for 67% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.5.1(b) an ARIMA(4,1,0) model was fitted to the data. This model accounted for 66% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the ARIMA(3,0,0) model and fitted to the data. This ARIMA(3,0,0)(1,0,0)84 model also accounted for 67% of the total variance.

4.5.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.5.2(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.5.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.5.2(b), and the structure of the ACF and PACF, Figure 4.5.2(b) & (c), an ARIMA(3,0,0) model was

fitted to the data. This model accounted for 76% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.5.2(b) an ARIMA(4,1,0) model was fitted to the data. This model also accounted for 76% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was added to the above models but there was no significant improvement in either model.

4.5.3. Vertical Solar Irradiance

The time series plot, Figure 4.5.3(a), displays daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.5.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.5.3(b), and the structure of the ACF and PACF, Figure 4.5.3(b) & (c), an ARIMA(3,0,0) model was fitted to the data. This model accounted for 74% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.5.3(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 72% of the total variance but the ACF of the residuals had a significant value at lag3. An ARIMA(3,1,0) model was then fitted to the data. This model also accounted for 72% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was added to the above models but there was no significant improvement in the models.

4.5.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.5.4(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.5.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.5.4(b), and the structure of the ACF and PACF, Figure 4.5.4(b) & (c), an ARIMA(3,0,0) model was fitted to the data. However, the backforecasts did not die out rapidly and this model was rejected. An ARIMA(1,0,0) model accounted for 84% of the total variance but the ACF of the residuals was not consistent with a 'white noise' process and this model was also rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.5.4(b) an ARIMA(4,1,0) model was fitted to the data. This model accounted for 84% of the total variance and the ACF of the residuals showed no structure.

Table 4.5.1 Summary information for Horizontal Solar Irradiance - 10 minute averages (datafile JUN94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.3552	0.2377	0.0174	0.9780

b)

$2/\sqrt{756}=0.073$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.807	0.807	-0.196	-0.196
2	0.691	0.111	-0.211	-0.260
3	0.655	0.202	0.061	-0.048
4	0.596	0.002	-0.046	-0.108
84	0.263	-0.025	-0.063	-0.052

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1	0.6971	0.0357	19.51	13.9560	0.186	67
	AR2	-0.0350	0.0438	-0.80			
	AR3	0.2043	0.0357	5.72			
	CONST	0.0467	0.00496	9.42			
ARIMA(3,0,0)(1,0,0)84	AR1	0.7007	0.0358	19.55	13.9499	0.0186	67
	AR2	-0.0364	0.0439	-0.83			
	AR3	0.2041	0.0358	5.71			
	SAR84	-0.0235	0.0386	-0.61			
	CONST	0.04709	0.0049	9.50			
ARIMA(4,1,0)	AR1	-0.2651	0.0363	-7.30	14.3991	0.0192	66
	AR2	-0.3019	0.0375	-8.06			
	AR3	-0.0761	0.0375	-2.03			
	AR4	-0.1086	0.0363	-2.99			

Table 4.5.2 Summary information for Log Transformed Horizontal Solar Irradiance - 10 minute averages (datafile JUN94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.3227	0.8419	-4.0513	-0.022

b)

$2/\sqrt{756}=0.073$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.871	0.871	-0.050	-0.050
2	0.757	-0.005	-0.196	-0.199
3	0.694	0.147	-0.036	-0.061
4	0.639	0.021	-0.065	-0.116
84	0.327	-0.005	-0.021	-0.001

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1	0.8879	0.0362	24.51	124.654	0.166	76
	AR2	-0.1457	0.0483	-3.01			
	AR3	0.1502	0.0362	4.14			
	CONST	-0.1450	0.0148	-9.78			
ARIMA(3,0,0)(1,0,0)84	AR1	0.8863	0.0363	24.39	124.640	0.166	76
	AR2	-0.1453	0.0484	-3.01			
	AR3	0.1508	0.0363	4.16			
	SAR84	0.0108	0.0382	0.28			
	CONST	-0.1440	0.01482	-9.72			
ARIMA(4,1,0)	AR1	-0.0811	0.0364	-2.23	127.878	0.170	76
	AR2	-0.2296	0.0364	-6.30			
	AR3	-0.0710	0.0365	-1.95			
	AR4	-0.1176	0.0364	-3.23			

Table 4.5.3 Summary information for Vertical Solar Irradiance - 10 minute averages (datafile JUN94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1889	0.1669	0.0100	0.7032

b)

$2/\sqrt{756}=0.073$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.850	0.850	-0.165	-0.165
2	0.749	0.096	-0.202	-0.236
3	0.708	0.187	0.024	-0.061
4	0.661	0.023	-0.005	-0.066
84	0.316	-0.061	-0.054	-0.066

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1	0.7500	0.0358	20.94	5.55037	0.00738	74
	AR2	-0.0471	0.0450	-1.05			
	AR3	0.1892	0.0358	5.28			
	CONST	0.0199	0.0031	6.37			
ARIMA(3,0,0)(1,0,0)84	AR1	0.7541	0.0361	20.91	5.54841	0.00739	73
	AR2	-0.0501	0.0452	-1.11			
	AR3	0.1898	0.0358	5.29			
	SAR84	-0.0210	0.0384	-0.55			
	CONST	0.02004	0.00312	6.41			
ARIMA(2,1,0)	AR1	-0.2041	0.0384	-5.76	5.76763	0.007676	72
	AR2	-0.2359	0.0354	-6.66			
ARIMA(2,1,0)(1,0,0)84	AR1	-0.1986	0.0356	-5.57	5.76237	0.00766	72
	AR2	-0.2357	0.0355	-6.65			
	SAR84	-0.0321	0.0383	-0.84			

Table 4.5.4 Summary information for Log Transformed Vertical Solar Irradiance - 10 minute averages (datafile JUN94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0802	0.9613	-4.6052	-0.3521

b)

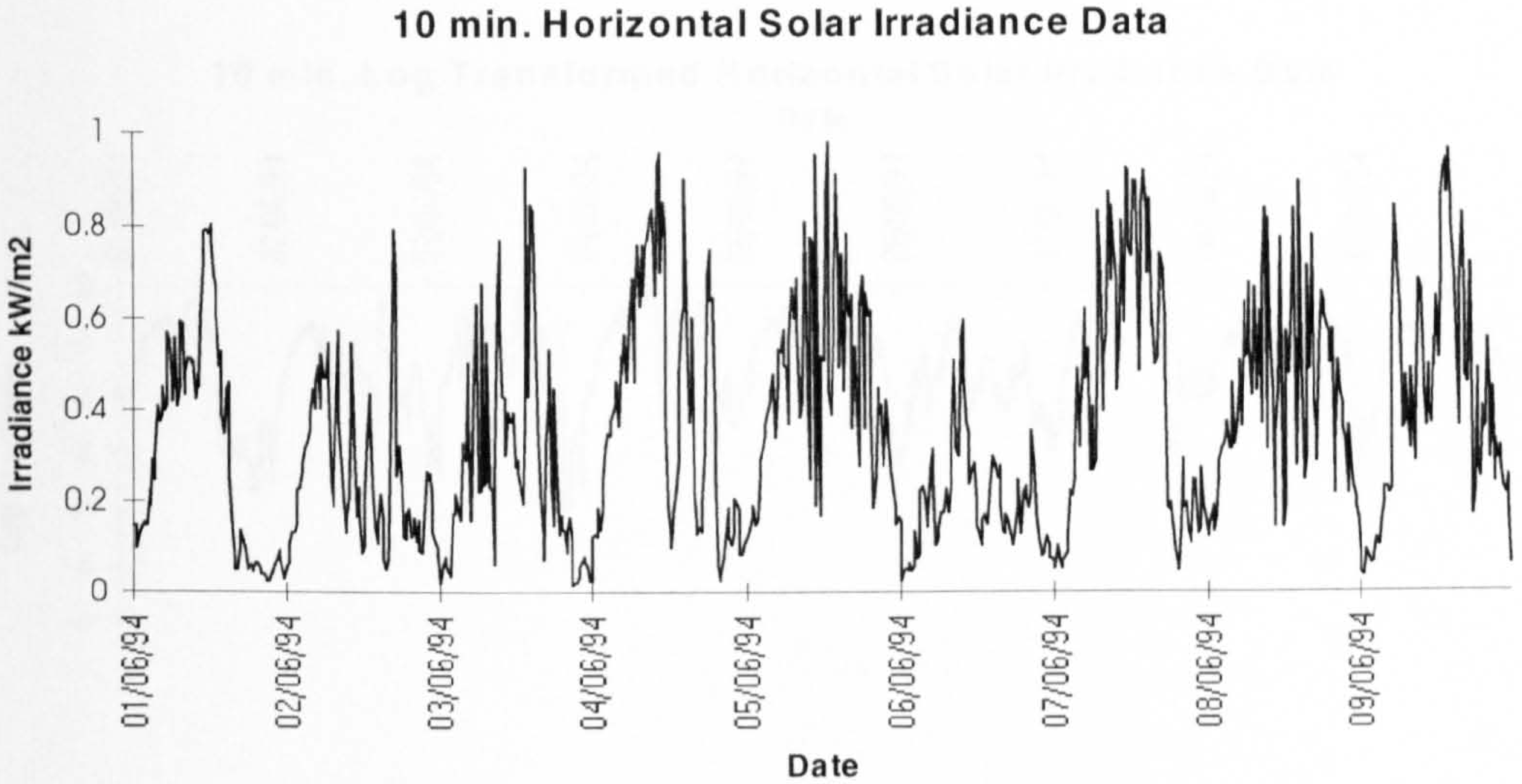
$2/\sqrt{756}=0.073$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.913	0.913	-0.011	-0.011
2	0.828	-0.031	-0.191	-0.191
3	0.776	0.151	-0.028	-0.034
4	0.729	0.004	-0.055	-0.096
84	0.453	0.001	-0.024	-0.017

c)

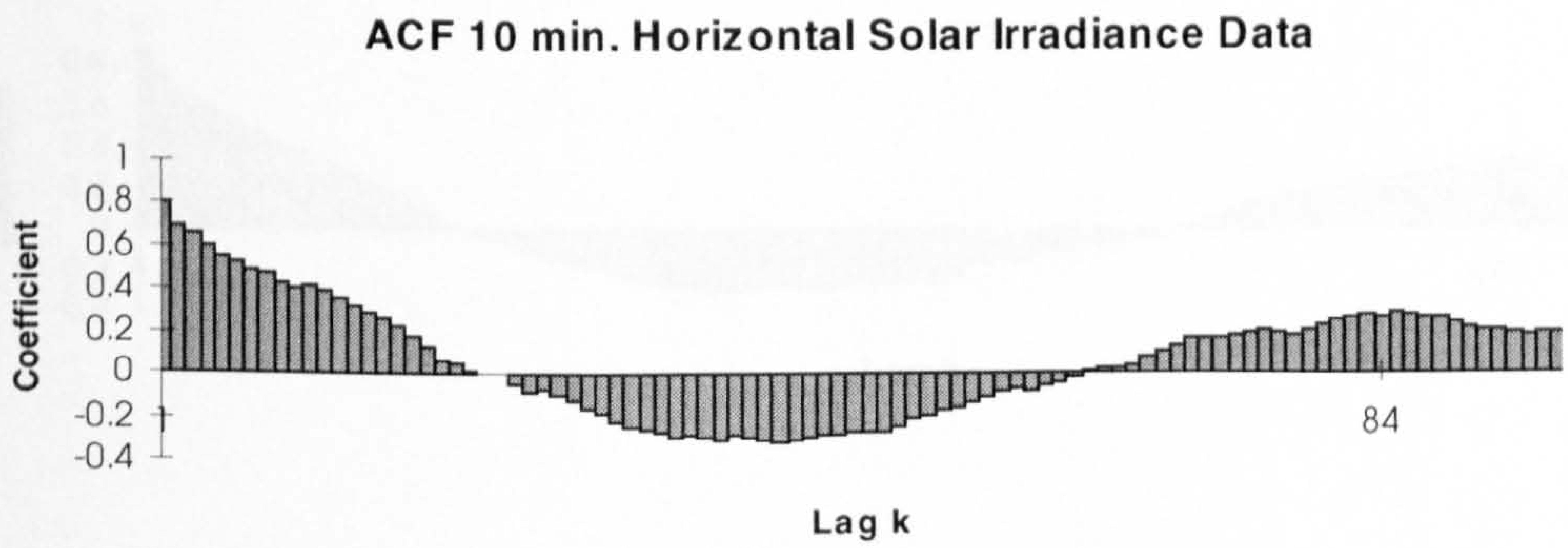
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(4,1,0)	AR1	-0.0226	0.0363	-0.62	113.133	0.151	84
	AR2	-0.2107	0.0363	-5.80			
	AR3	-0.0359	0.0363	-0.99			
	AR4	-0.0961	0.0364	-2.64			
ARIMA(2,1,0)(1,0,0)84	AR1	-0.0116	0.0359	-0.32	114.305	0.152	78
	AR2	-0.1911	0.0358	-5.33			
	SAR84	-0.0099	0.0378	-0.26			

Figure 4.5.1 Horizontal Solar Irradiance - 10 minute averages, JUN94_10

a)



b)



c)

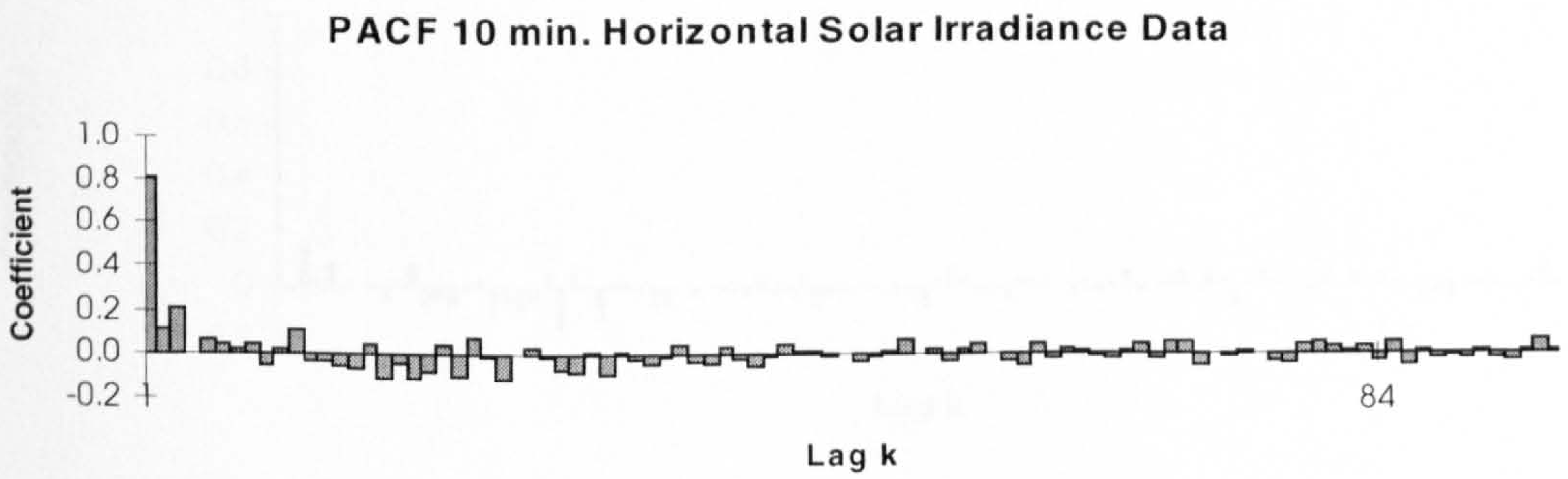
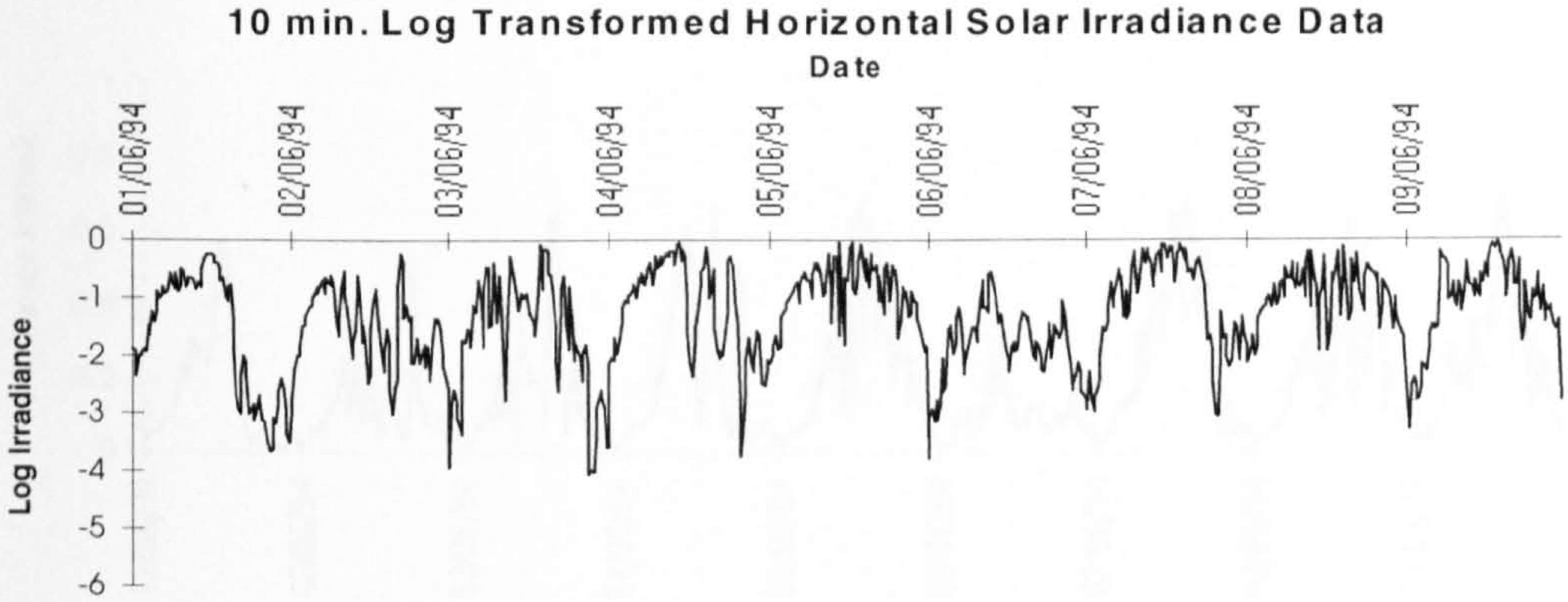
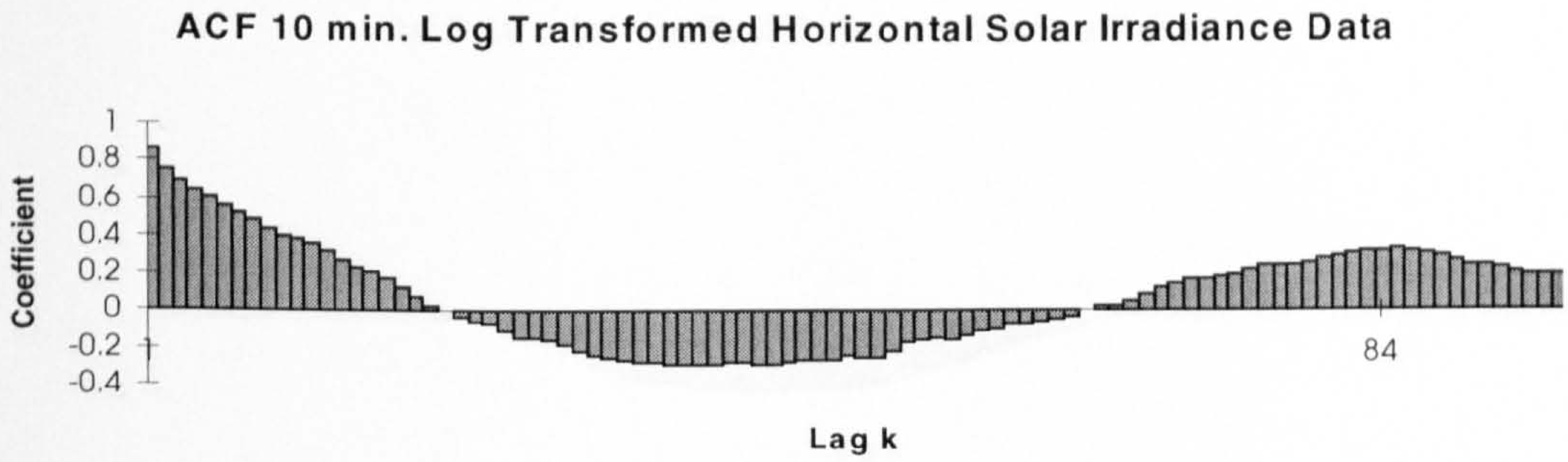


Figure 4.5.2 Log transformed Horizontal Solar Irradiance - 10 minute averages, JUN94_10

a)



b)



c)

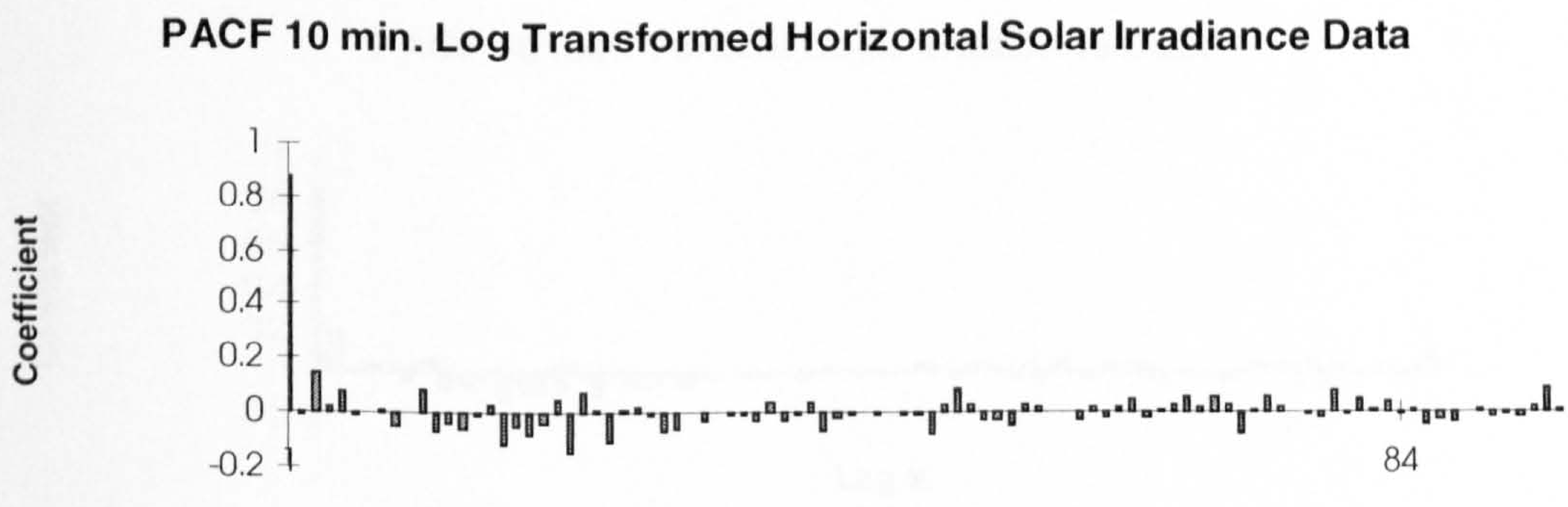
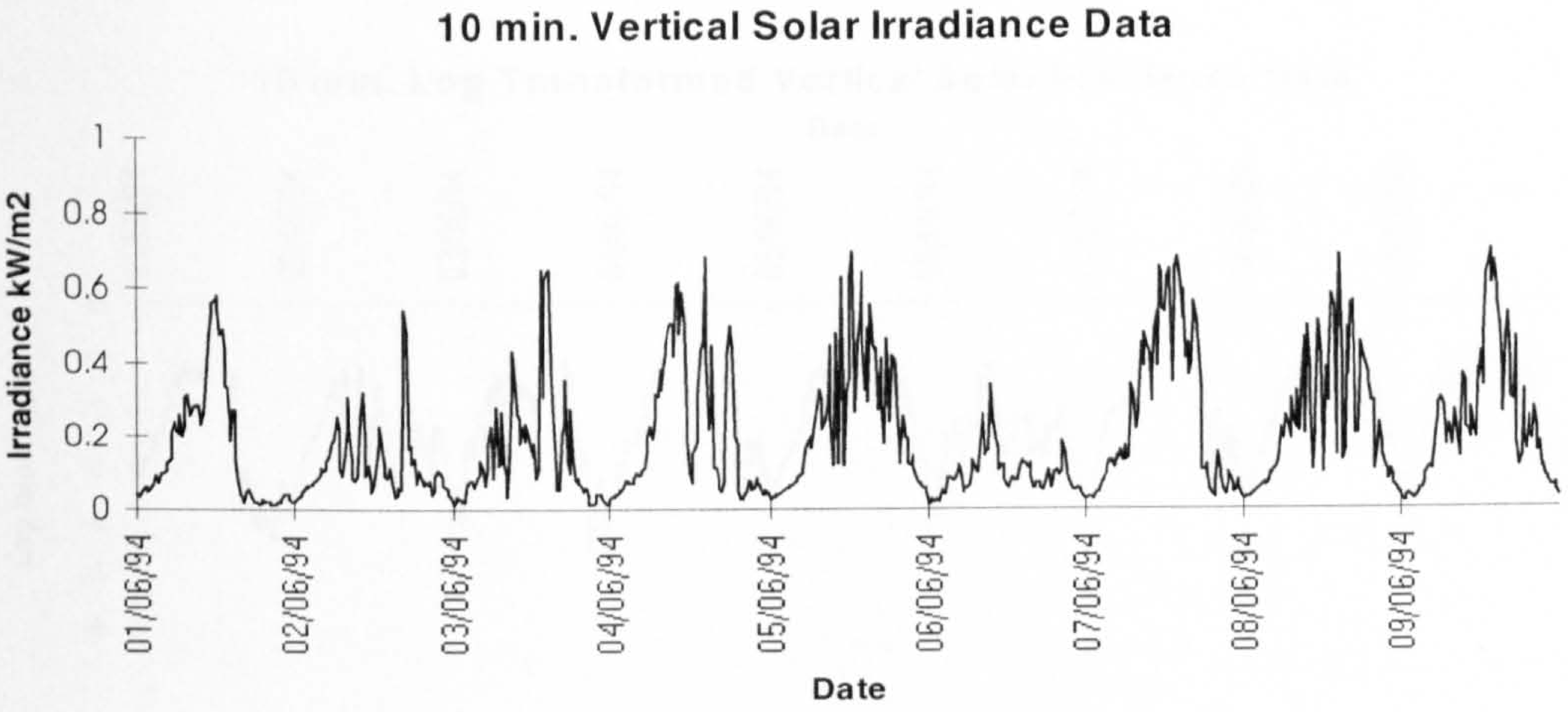
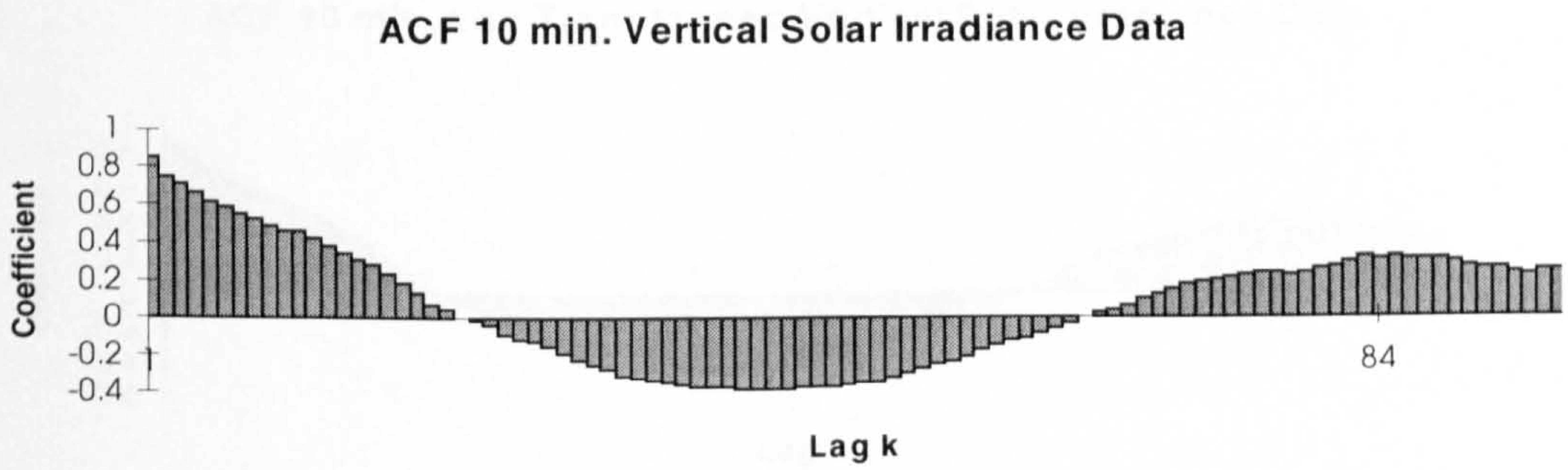


Figure 4.5.3 Vertical Solar Irradiance - 10 minute averages, JUN94_10

a)



b)



c)

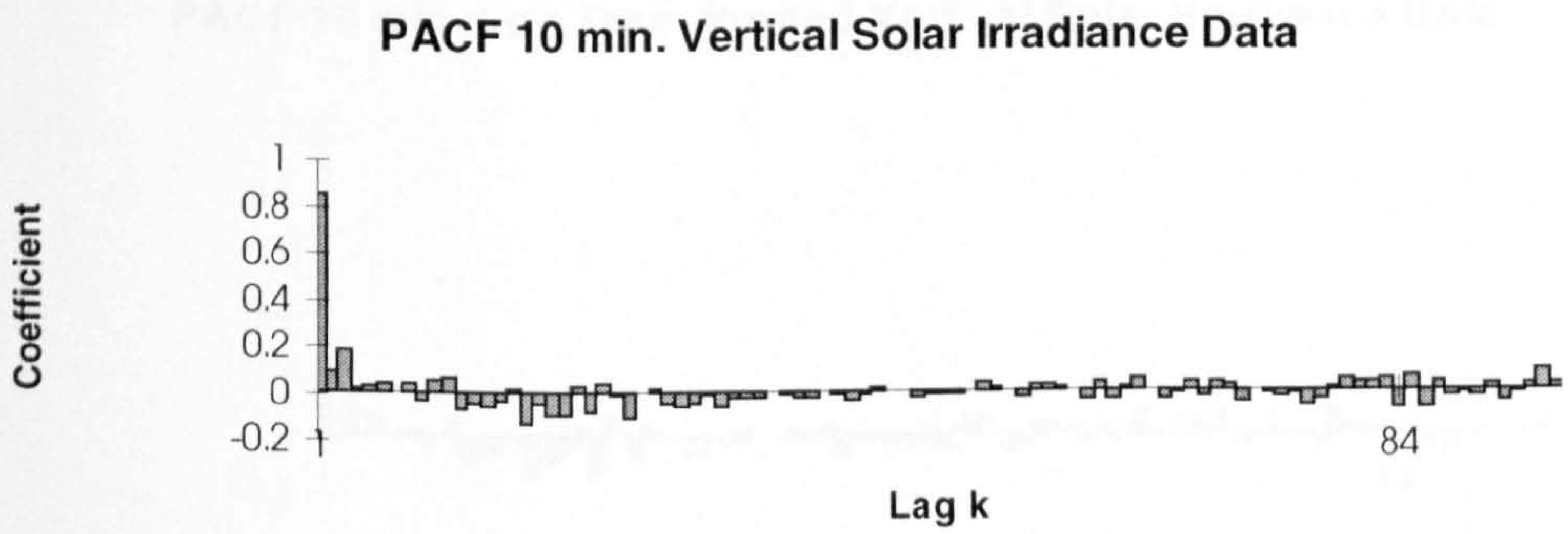
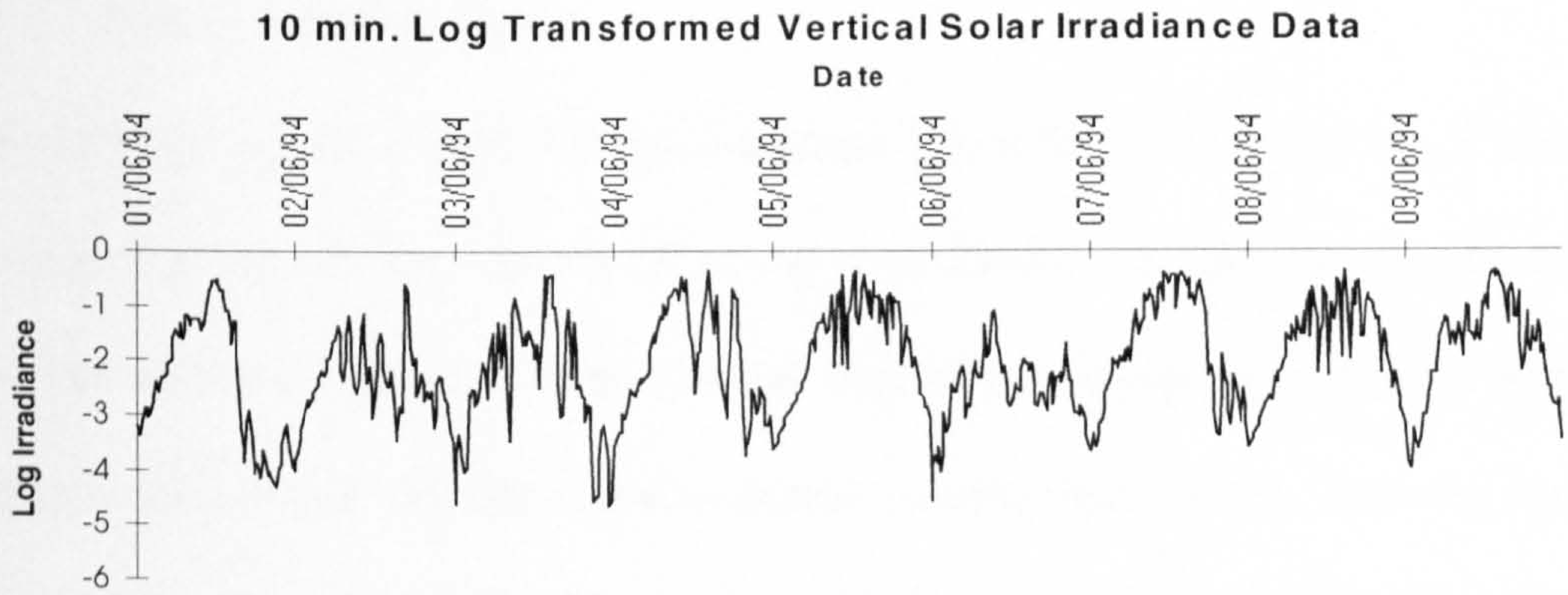
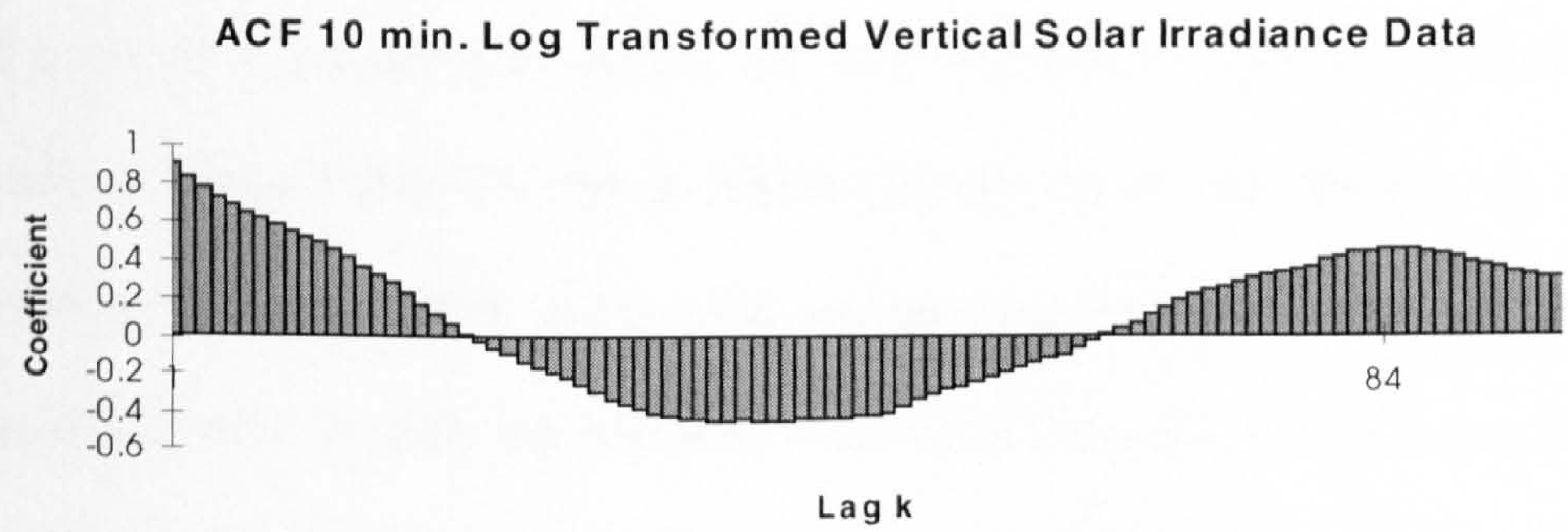


Figure 4.5.4 Log transformed Vertical Solar Irradiance - 10 minute averages, JUN94_10

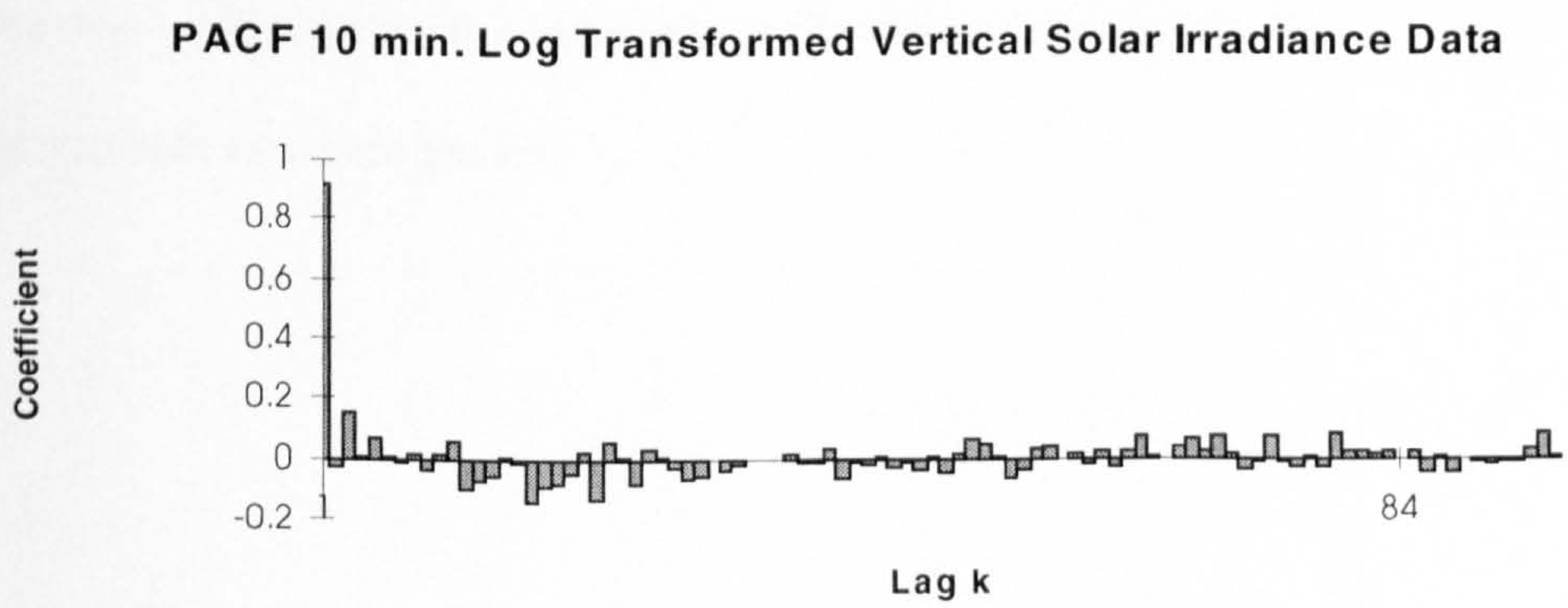
a)



b)



c)



4.6. June 1994 (1st - 9th) - Twenty minute averages

This data set, known as JUN94_20, contains 20 minute averaged Horizontal and Vertical Solar Irradiance data recorded between 1st and 9th June 1994.

4.6.1. Horizontal Irradiance

The time series plot, Figure 4.6.1(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.6.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.6.1(b), and the structure of the ACF and PACF, Figure 4.6.1(b) & (c), an ARIMA(2,0,0) model was fitted to the data. This model accounted for 62% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.6.1(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 60% of the total variance but the ACF of the residuals had a significant value at lag3. An ARIMA(3,1,0) model was fitted to the data, this model also accounted for 60% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was added to the above models but there was no significant improvement in either model.

4.6.2. Log Transform of Horizontal Irradiance

The time series plot, Figure 4.6.2(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.6.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.6.2(b), and the structutre of the ACF and PACF, Figure 4.6.2(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 68% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.6.2(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 66% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was added to the above models but there was no significant improvement in either model.

4.6.3. Vertical Irradiance

The time series plot, Figure 4.6.3(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.6.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.6.3(b), and the structure of the ACF and PACF, Figure 4.6.3(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 68% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.6.3(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 67% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was added to the above models but there was no significant improvement in either model.

4.6.4. Log Transform of Vertical Irradiance

The time series plot, Figure 4.6.4(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.6.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.6.4(b), and the structure of the ACF and PACF, Figure 4.6.4(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 77% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.6.4(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 76% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was added to the above models but there was no significant improvement in either model.

Table 4.6.1 Summary information for Horizontal Solar Irradiance - 20 minute averages (datafile JUN94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.3552	0.2265	0.0186	0.9316

b)

$2/\sqrt{378}=0.103$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.783	0.783	-0.218	-0.218
2	0.660	0.123	-0.105	-0.160
3	0.584	0.089	-0.007	-0.074
4	0.511	0.015	-0.026	-0.068
42	0.289	-0.015	-0.027	-0.043

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,0,0)	AR1	0.6895	0.0513	13.44	7.29531	0.01945	62
	AR2	0.1245	0.0513	2.43			
	CONST	0.0650	0.00717	9.06			
ARIMA(2,0,0)(1,0,0)42	AR1	0.6800	0.0518	13.14	7.28633	0.1948	62
	AR2	0.1298	0.0515	2.52			
	SAR42	0.0385	0.0555	0.69			
	CONST	0.06395	0.00718	8.90			
ARIMA(2,1,0)	AR1	-0.2535	0.0510	-4.97	7.65249	0.02046	60
	AR2	-0.1609	0.0510	-3.15			
ARIMA(2,1,0)(1,0,0)42	AR1	-0.2648	0.0515	-5.15	7.68072	0.02054	60
	AR2	-0.1683	0.0511	-3.29			
	SAR42	0.0478	0.0558	0.86			

Table 4.6.2 Summary information for Log Transformed Horizontal Solar Irradiance - 20 minute averages (datafile JUN94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.3019	0.8116	-3.9819	-0.0709

b)

$2/\sqrt{378}=0.103$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.823	0.823	-0.119	-0.119
2	0.689	0.037	-0.136	-0.152
3	0.603	0.087	0.007	-0.031
4	0.516	-0.028	-0.034	-0.061
42	0.354	0.029	0.033	0.021

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8261	0.0292	28.29	79.4910	0.2114	68
	CONST	-0.2294	0.0236	-9.70			
ARIMA(1,0,0)(1,0,0)42	AR1	0.8149	0.0302	27.0	78.9984	0.2107	68
	SAR42	0.0838	0.0540	1.55			
	CONST	-0.2237	0.02362	-9.47			
ARIMA(2,1,0)	AR1	-0.1382	0.0512	-2.70	83.8039	0.2235	66
	AR2	-0.1532	0.0512	-2.99			
ARIMA(2,1,0)(1,0,0)42	AR1	-0.1553	0.0513	-3.03	83.2768	0.2227	66
	AR2	-0.1534	0.0512	-3.00			
	SAR42	0.0968	0.0541	1.79			

Table 4.6.3 Summary information for Vertical Solar Irradiance - 20 minute averages (datafile JUN94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1889	0.1608	0.0104	0.6846

b)

$2/\sqrt{378}=0.103$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.823	0.823	-0.180	-0.180
2	0.710	0.099	-0.104	-0.141
3	0.633	0.078	0.002	-0.047
4	0.555	-0.009	-0.057	-0.086
42	0.339	0.008	0.003	-0.034

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8270	0.0291	28.39	3.10665	0.00826	68
	CONST	0.0321	0.0047	6.86			
ARIMA(1,0,0)(1,0,0)42	AR1	0.8216	0.0297	27.66	3.10143	0.00827	68
	SAR42	0.0432	0.0544	0.79			
	CONST	0.03166	0.00468	6.77			
ARIMA(2,1,0)	AR1	-0.2055	0.0511	-4.02	3.22613	0.00860	67
	AR2	-0.1410	0.0511	-2.76			
ARIMA(2,1,0)(1,0,0)42	AR1	-0.2188	0.0515	-4.25	3.21566	0.00860	66
	AR2	-0.1490	0.0512	-2.91			
	SAR42	0.0619	0.0548	1.13			

Table 4.6.4 Summary information for Log Transformed Vertical Solar Irradiance - 20 minute averages (datafile JUN94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0617	0.9440	-4.5659	-0.3789

b)

$2/\sqrt{378}=0.103$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.875	0.875	-0.054	-0.054
2	0.765	-0.004	-0.132	-0.136
3	0.688	0.084	-0.013	-0.029
4	0.615	-0.016	-0.015	-0.037
42	0.476	0.020	0.011	-0.014

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)	AR1	0.8823	0.0246	35.88	76.3092	0.2029	77
	CONST	-0.2479	0.0232	-10.69			
ARIMA(1,0,0)(1,0,0)42	AR1	0.8750	0.0254	34.40	76.0846	0.2029	77
	SAR42	0.0566	0.0537	1.05			
	CONST	-0.2479	0.02319	-10.7			
ARIMA(2,1,0)	AR1	-0.0619	0.0512	-1.21	79.3092	0.2118	76
	AR2	-0.1362	0.0512	-2.66			
ARIMA(2,1,0)(1,0,0)42	AR1	-0.0830	0.0517	-1.61	79.1254	0.2116	76
	AR2	-0.1491	0.0513	-2.91			
	SAR42	0.0686	0.0543	1.26			

Figure 4.6.1 Horizontal Solar Irradiance - 20 minute averages, JUN94_20

a)

b)

c)

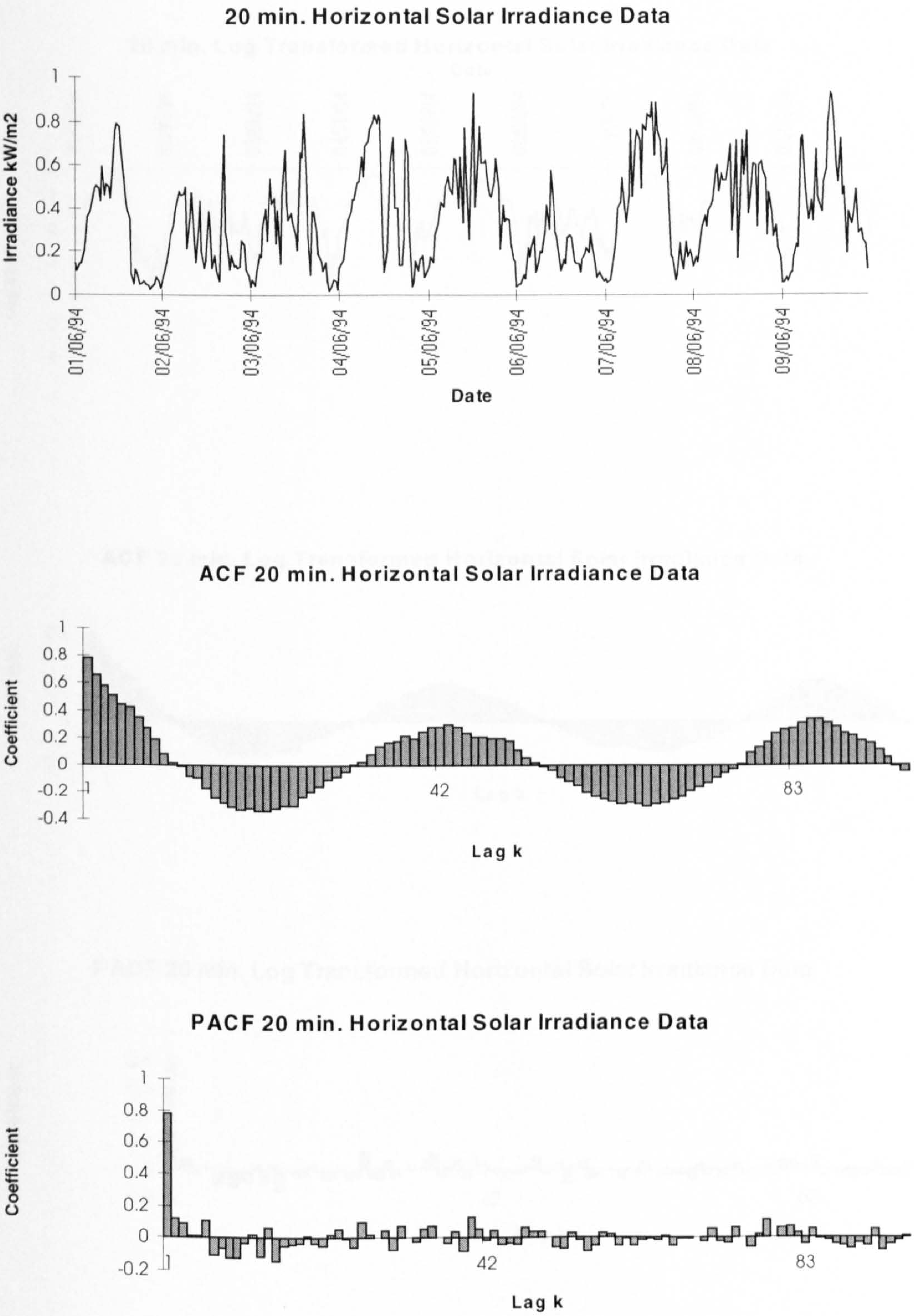
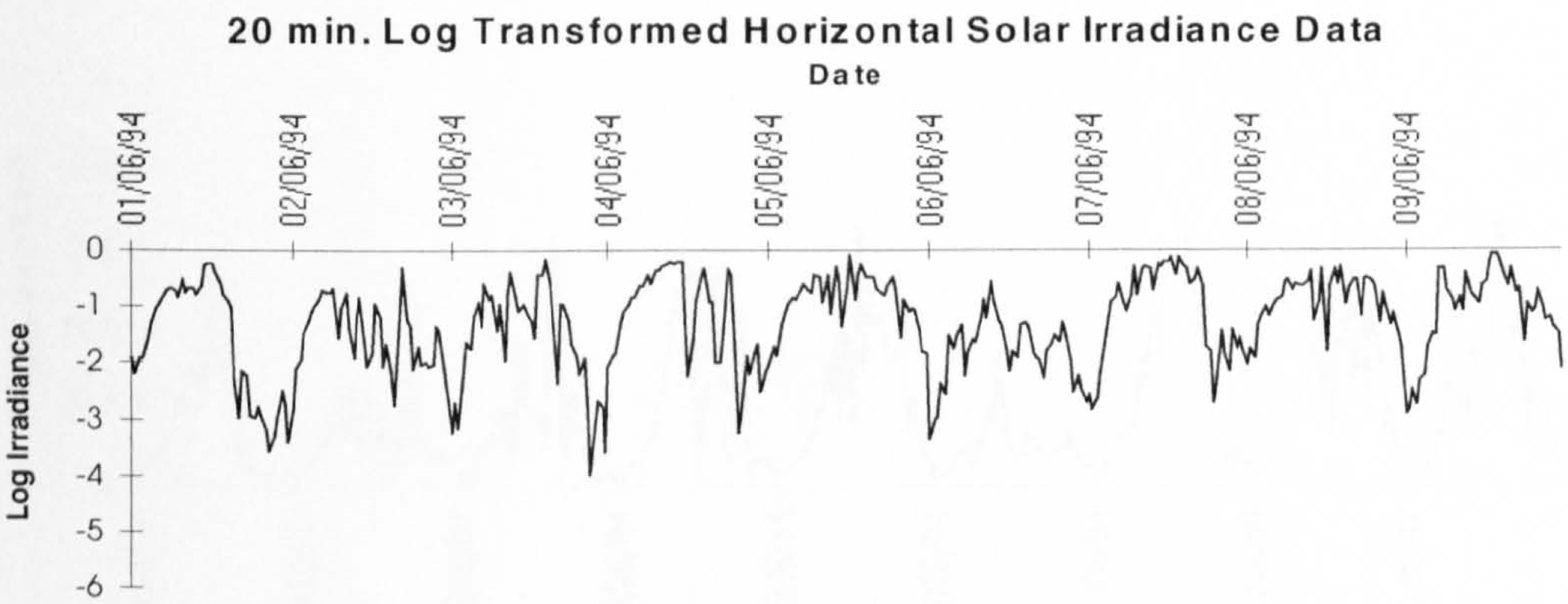
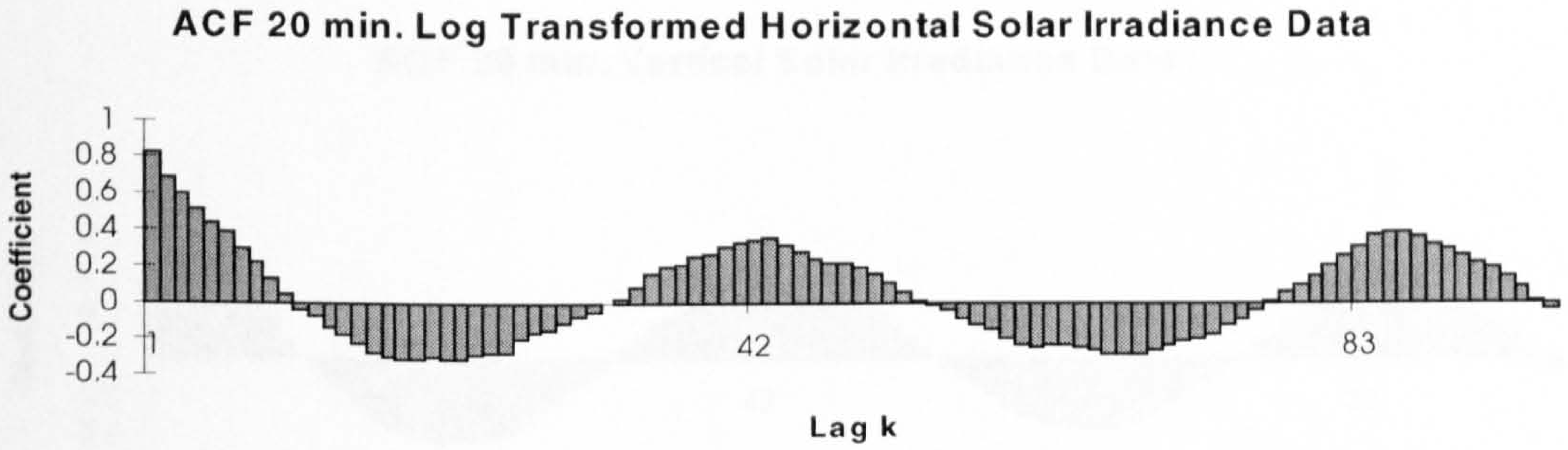


Figure 4.6.2 Log transformed Horizontal Solar Irradiance - 20 minute averages, JUN94_20

a)



b)



c)

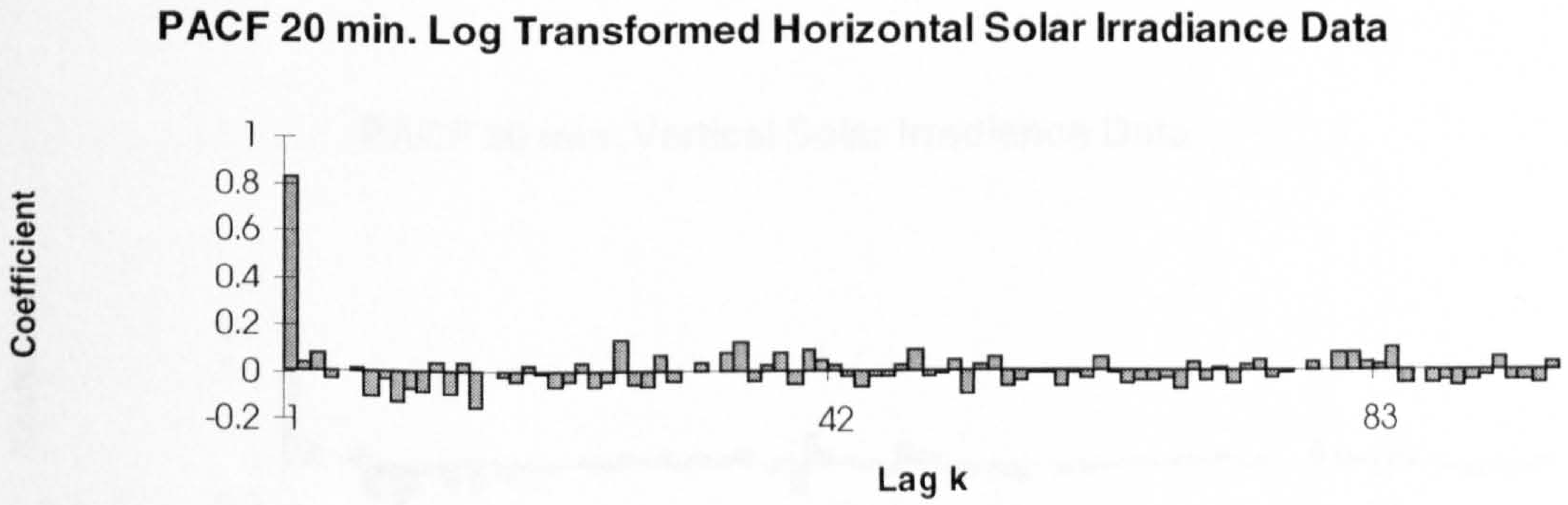
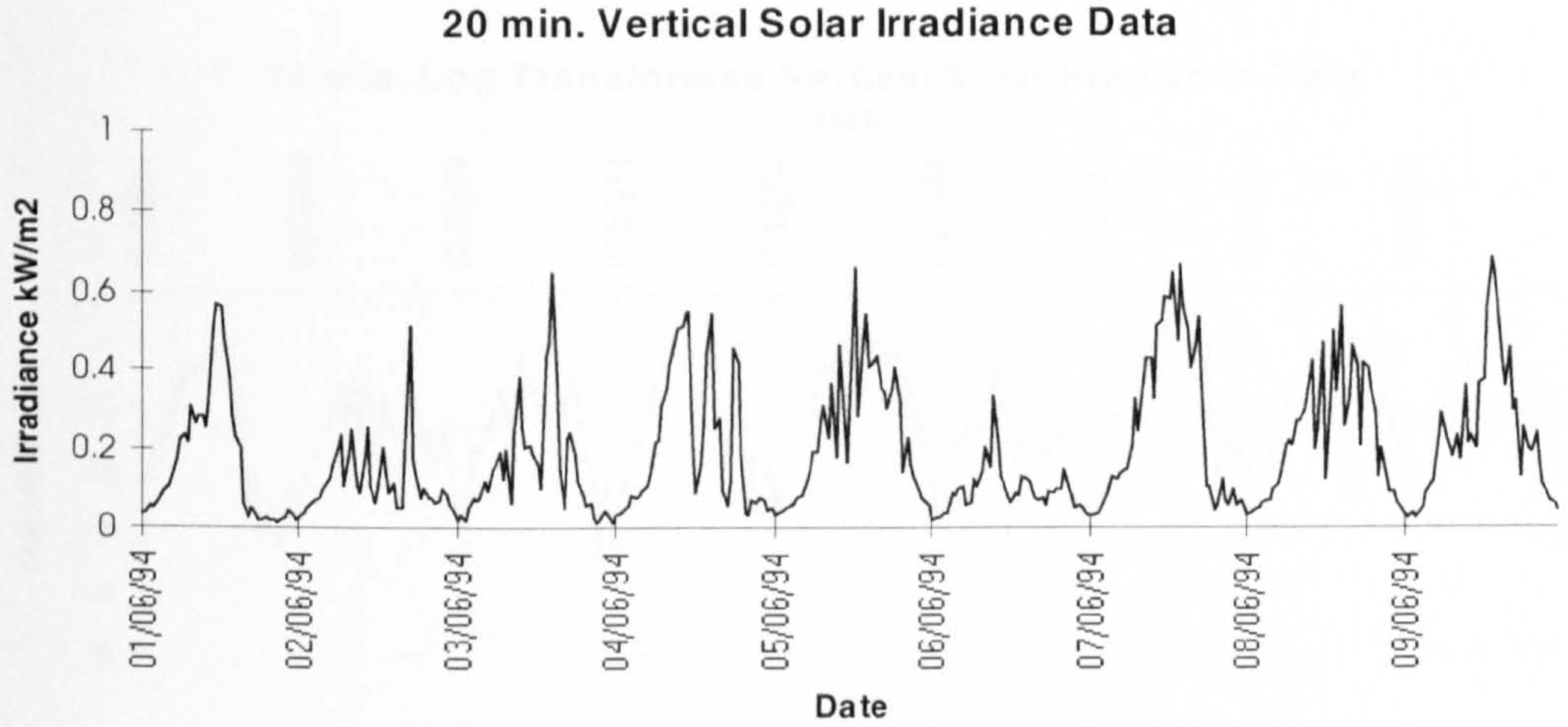
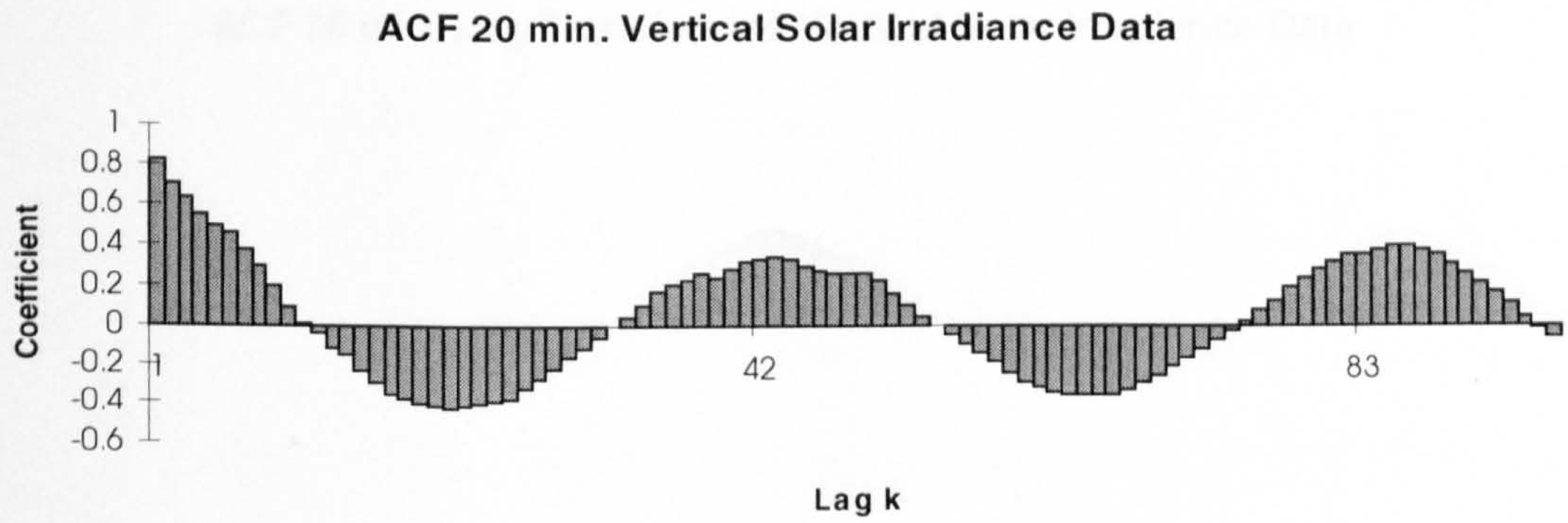


Figure 4.6.3 Vertical Solar Irradiance - 20 minute averages, JUN94_20

a)



b)



c)

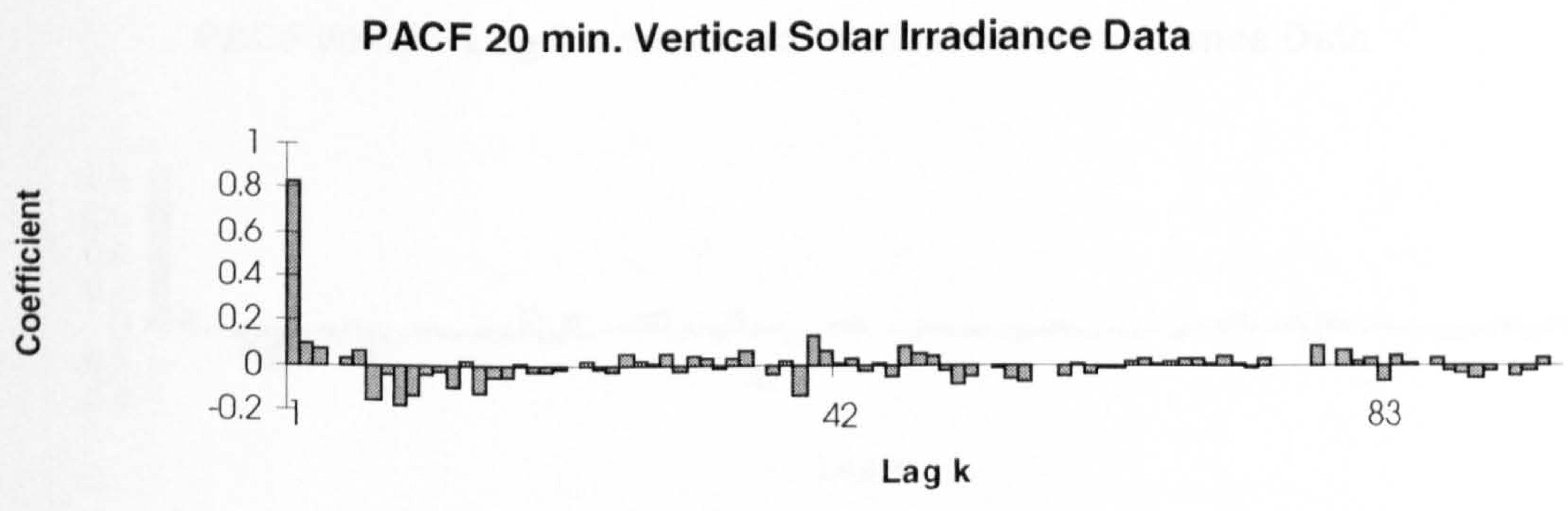
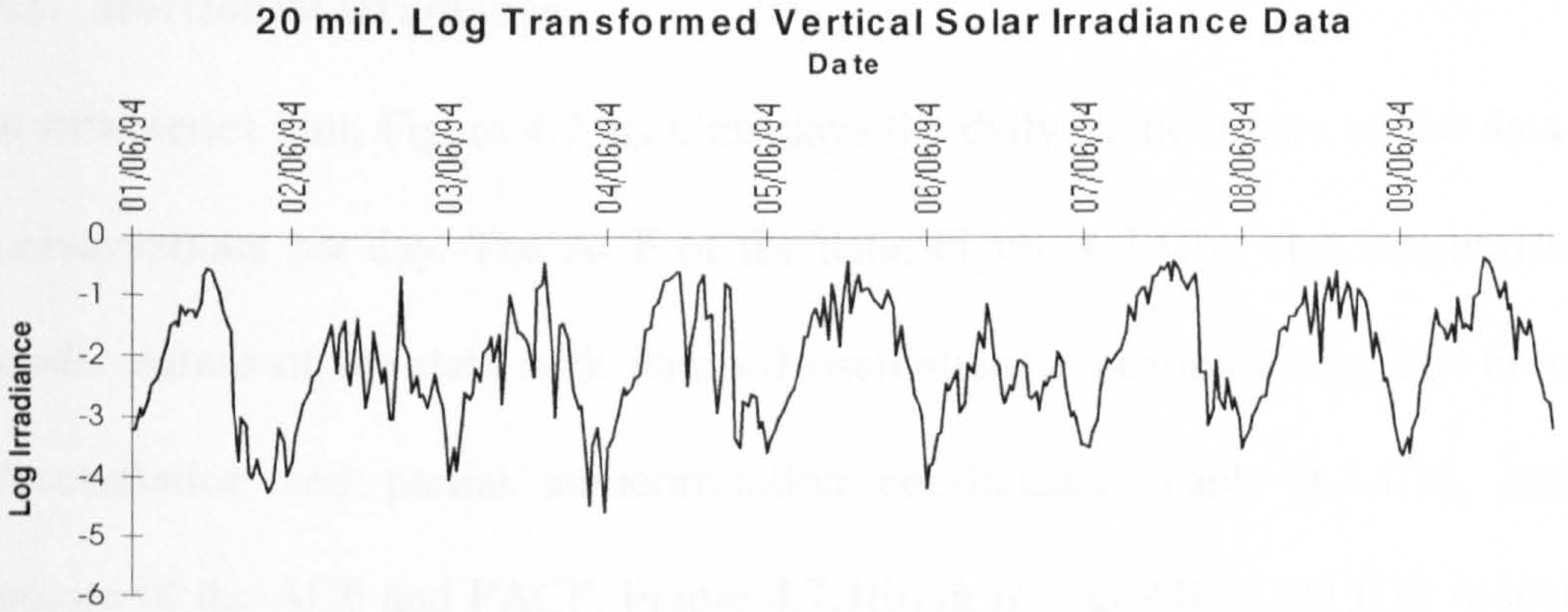
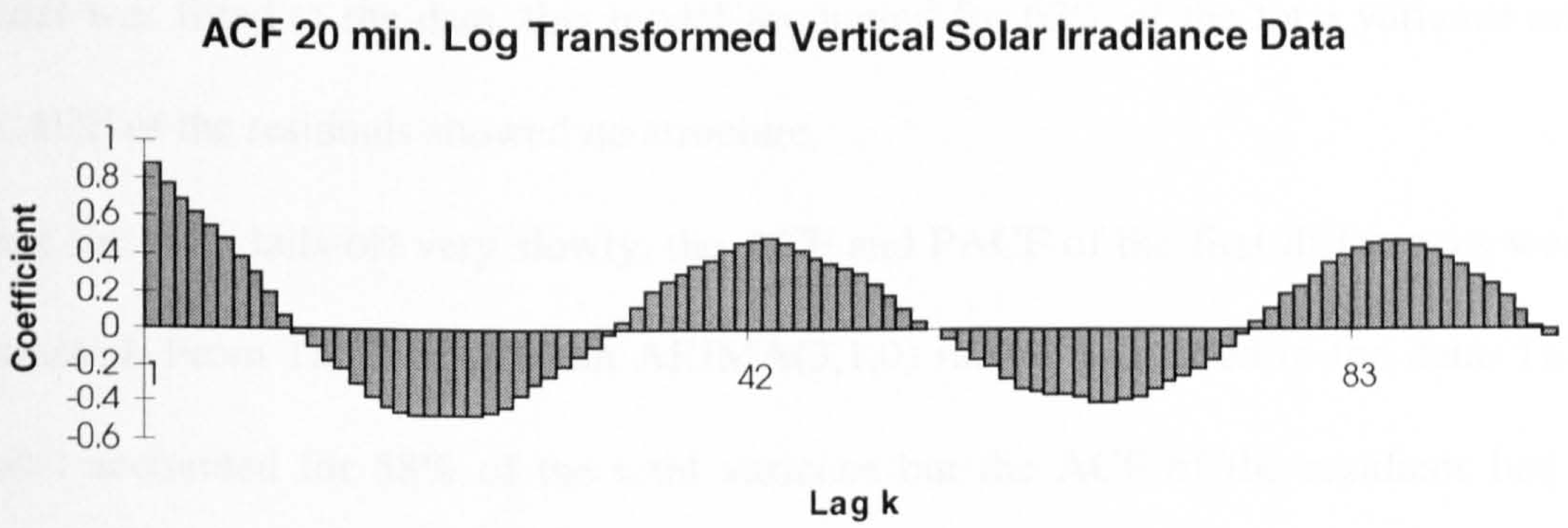


Figure 4.6.4 Log transformed Vertical Solar Irradiance - 20 minute averages, JUN94_20

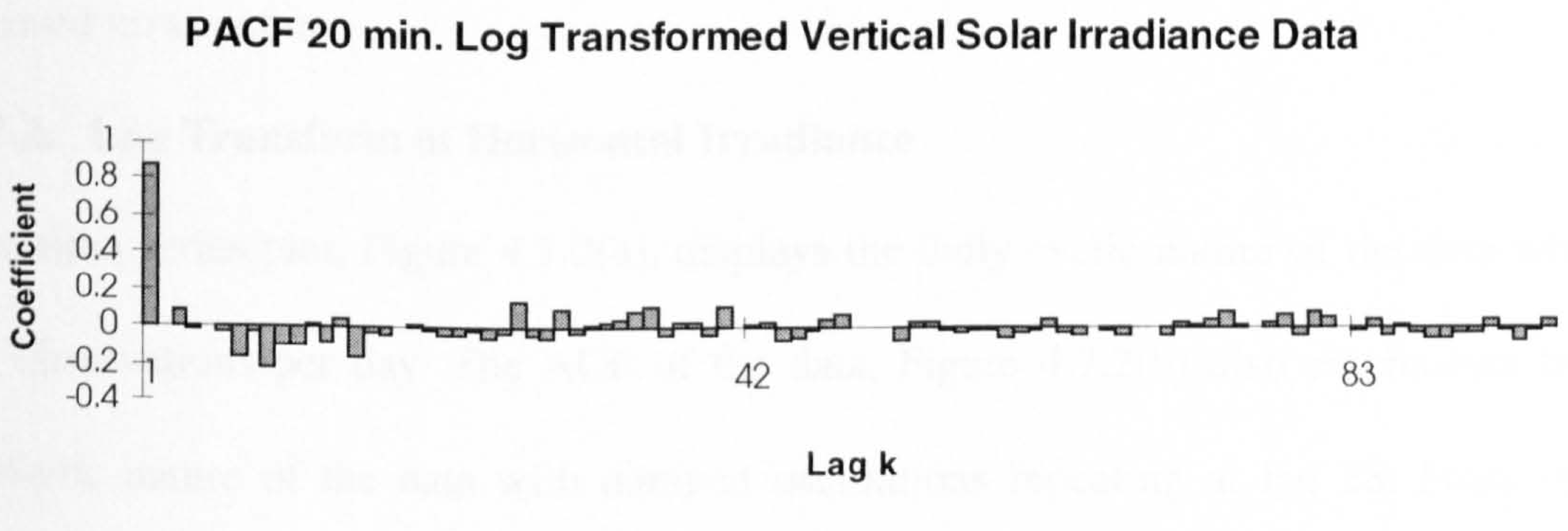
a)



b)



c)



4.7. June 1994 (1st - 9th) - Thirty minute averages

This data set, known as JUN94_30, contains 30 minute averaged Horizontal and Vertical Solar Irradiance data recorded between 1st and 9th June 1994.

4.7.1. Horizontal Irradiance

The time series plot, Figure 4.7.1(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.7.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.7.1(b), and the structure of the ACF and PACF, Figure 4.7.1(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 61% of the total variance but the ACF of the residuals had significant values at lag 4 and lag 28. An ARIMA(1,0,0)(1,0,0)28 model was fitted to the data, this model accounted for 62% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.7.1(b) an ARIMA(3,1,0) model was fitted to the data. This model accounted for 58% of the total variance but the ACF of the residuals had a significant value at lag 28. An ARIMA(3,1,0)(1,0,0)28 model was fitted to the data, this model accounted for 60% of the total variance and the ACF of the residuals showed no structure.

4.7.2. Log Transform of Horizontal Irradiance

The time series plot, Figure 4.7.2(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.7.2(b) also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.7.2(b), and the structure of the ACF and PACF, Figure 4.7.2(b) & (c), an ARIMA(1,0,0) model to the data. This model accounted for 64% of the total variance and the ACF of the residuals showed no structure. An ARIMA(1,0,0)1,0,0)28 model was also fitted to the data, this model accounted for 65% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.7.2(b) there is no structure to the ACF and PACF and an ARIMA model cannot be determined for the differenced data.

4.7.3. Vertical Irradiance

The time series plot, Figure 4.7.3(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.7.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.7.3(b), and the structure of the ACF and PACF, Figure 4.7.3(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 67% of the total variance but the ACF of the residuals had a significant value at lag28. An ARIMA(1,0,0)(1,0,0)28 model was then fitted to the data. This model accounted for 65% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.7.3(b) the ACF and PACF do not exhibit any structure and an ARIMA model cannot be determined for the differenced data.

4.7.4. Log Transform of Vertical Irradiance

The time series plot, Figure 4.7.4(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.7.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.7.4(b), and the structure of the ACF and PACF, Figure 4.7.4(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 74% of the total variance but the ACF of the residuals had a significant value at lag28. An ARIMA(1,0,0)(1,0,0)28 model was then fitted to the data, this model accounted for 75% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.7.3(b) the ACF and the PACF of the differenced series do not exhibit any structure and an ARIMA model cannot be determined for the differenced data.

Table 4.7.1 Summary information for Horizontal Solar Irradiance - 30 minute averages (datafile JUN94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.3552	0.2180	0.0277	0.9105

b)

$2/\sqrt{N}$=0.126	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.780	0.780	-0.170	-0.170
2	0.634	0.068	-0.069	-0.101
3	0.521	0.017	-0.98	-0.133
4	0.451	0.063	0.119	0.072
28	0.314	0.030	0.104	0.011

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.7853	0.0393	19.96	4.61337	0.01845	61
	CONST	0.0750	0.00856	8.76			
ARIMA(1,0,0)(1,0,0)28	AR1	0.7678	0.0409	18.75	4.50416	0.01809	62
	SAR28	0.1646	0.0666	2.47			
	CONST	0.06796	0.00848	8.02			
ARIMA(3,1,0)	AR1	-0.2012	0.0630	-3.19	4.88121	0.01968	58
	AR2	-0.1267	0.0638	-1.98			
	AR3	-0.1336	0.0630	-2.12			
ARIMA(3,1,0)(1,0,0)28	AR1	-0.2305	0.0633	-3.64	4.76722	0.01930	60
	AR2	-0.1343	0.0642	-2.09			
	AR3	-0.1351	0.0631	-2.14			
	SAR28	0.1664	0.0675	2.46			

Table 4.7.2 Summary information for Log Transformed Horizontal Solar Irradiance - 30 minute averages (datafile JUN94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.2855	0.7879	-3.5851	-0.0938

b)

2/√N=0.126	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.800	0.800	-0.115	-0.115
2	0.647	0.02	-0.016	-0.030
3	0.502	-0.058	-0.110	-0.117
4	0.403	0.035	0.062	0.035
28	0.373	0.008	0.115	0.027

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8043	0.0377	21.33	55.4164	0.2217	
	CONST	-0.2554	0.0297	-8.61			
ARIMA(1,0,0)(1,0,0)28	AR1	0.7809	0.0400	19.51	53.6708	0.2155	65
	SAR28	0.1874	0.0653	2.87			
	CONST	-0.2322	0.02926	-7.94			
ARIMA(3,1,0)(1,0,0)28	AR1	-0.1610	0.0634	-2.54	58.0533	0.2350	62
	AR2	-0.0547	0.0640	-0.85			
	AR3	-0.1240	0.0633	-1.96			
	SAR28	0.1830	0.0659	2.77			

Table 4.7.3 Summary information for Vertical Solar Irradiance - 30 minute averages (datafile JUN94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1889	0.1556	0.0139	0.6681

b)

$2/\sqrt{N}$=0.126	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.818	0.818	-0.118	-0.118
2	0.679	0.029	-0.075	-0.090
3	0.567	0.013	-0.070	-0.092
4	0.482	0.026	0.121	0.095
28	0.359	0.067	0.139	0.002

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8237	0.0361	22.82	1.9789	0.00792	
	CONST	0.0324	0.0056	5.78			
ARIMA(1,0,0)(1,0,0)28	AR1	0.8050	0.0380	21.20	1.91027	0.00767	68
	SAR28	0.2029	0.0649	3.13			
	CONST	0.02888	0.00552	5.23			
ARIMA(1,1,0)(1,0,0)28	AR1	-0.1307	0.0628	-2.08	2.09010	0.00839	65
	SAR28	0.1623	0.0654	2.48			

Table 4.7.4 Summary information for Log Transformed Vertical Solar Irradiance - 30 minute averages (datafile JUN94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0451	0.9287	-4.2735	-0.4033

b)

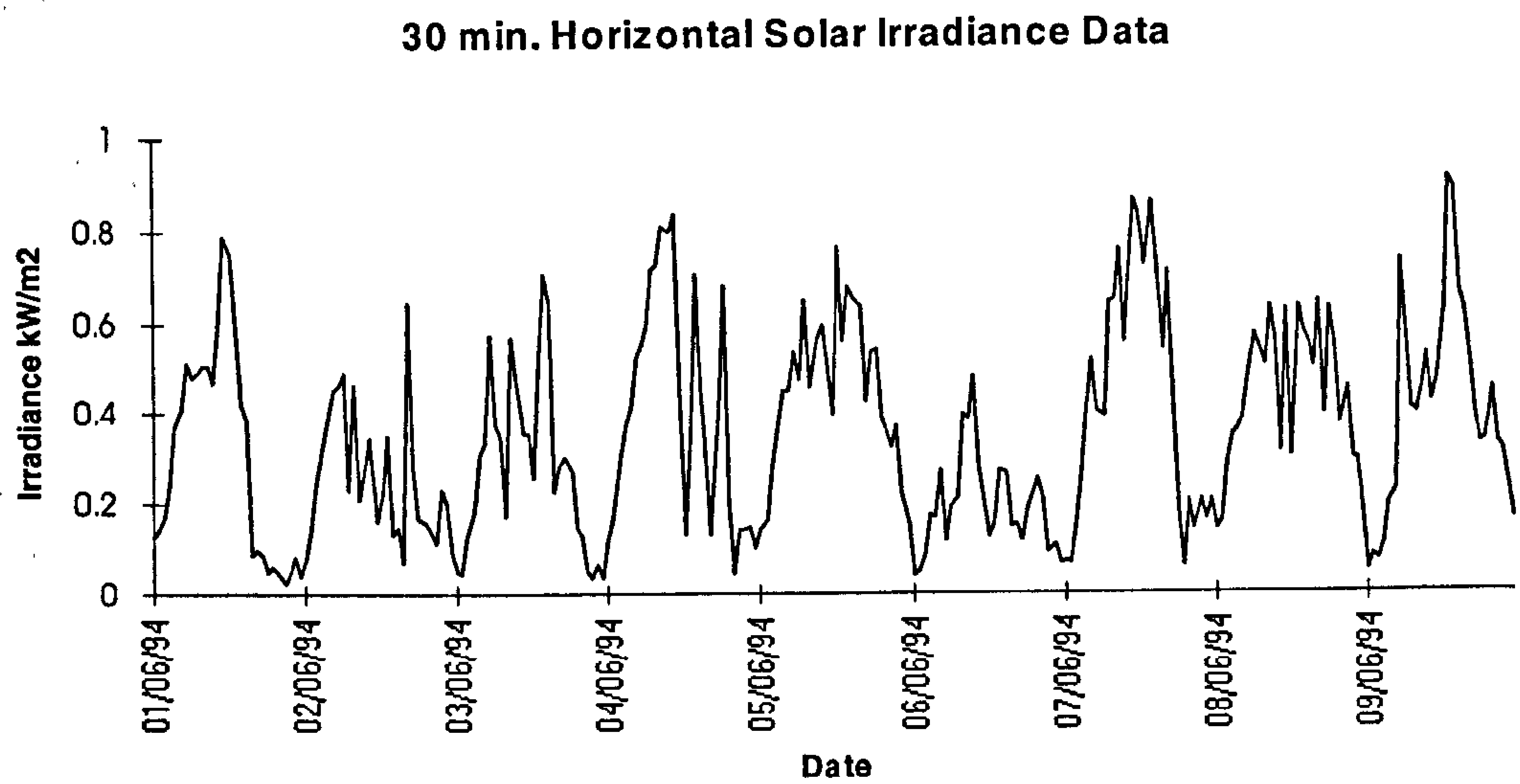
$2/\sqrt{N}=0.126$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.854	0.854	-0.053	-0.053
2	0.725	-0.013	-0.019	-0.022
3	0.605	-0.043	-0.033	-0.036
4	0.497	-0.023	0.117	0.114
28	0.502	-0.012	0.150	0.017

c)

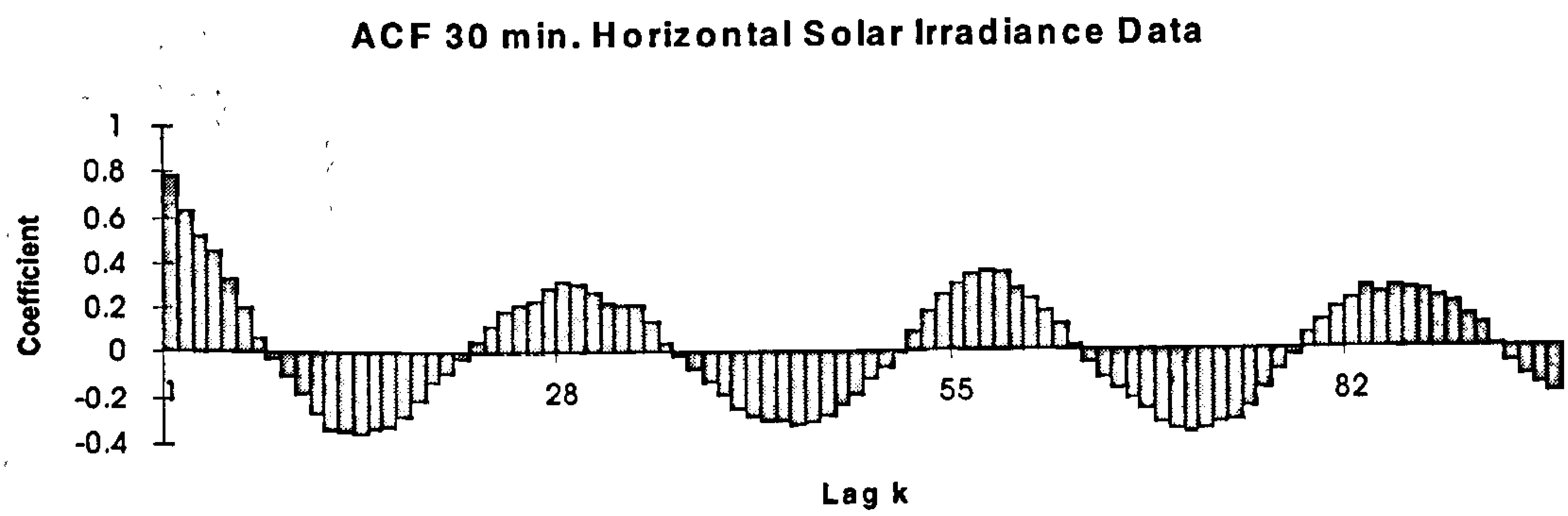
model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)28	AR1	0.8314	0.0358	23.20	53.9579	0.2167	75
	SAR28	0.2303	0.0637	3.61			
	CONST	-0.2706	0.0294	-9.21			
ARIMA(0,1,0)(1,0,0)28	SAR28	0.1717	0.0640	2.68	59.1606	0.2366	72
ARIMA(4,1,0)(1,0,0)28	AR1	-0.1205	0.0643	-1.87	57.8121	0.2350	72
	AR2	-0.0411	0.0642	-0.64			
	AR3	-0.0320	0.0643	-0.50			
	AR4	0.0754	0.0646	1.17			
	SAR28	0.2044	0.0659	3.10			

Figure 4.7.1 Horizontal Solar Irradiance - 30 minute averages, JUN94_30

a)



b)



c)

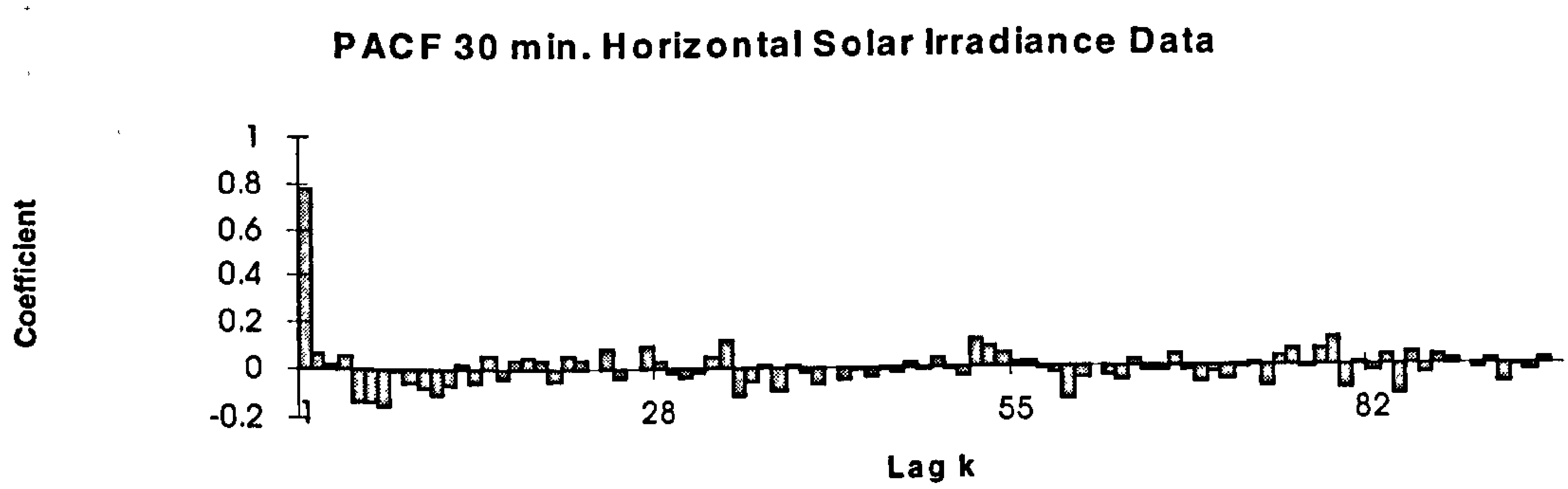
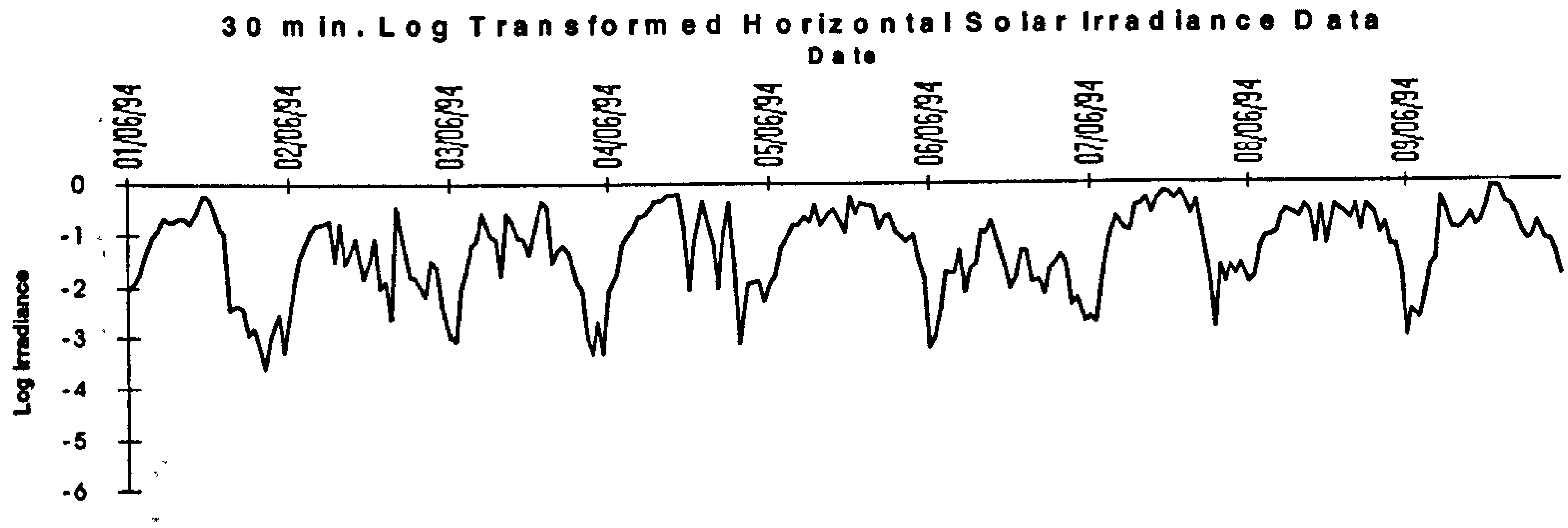
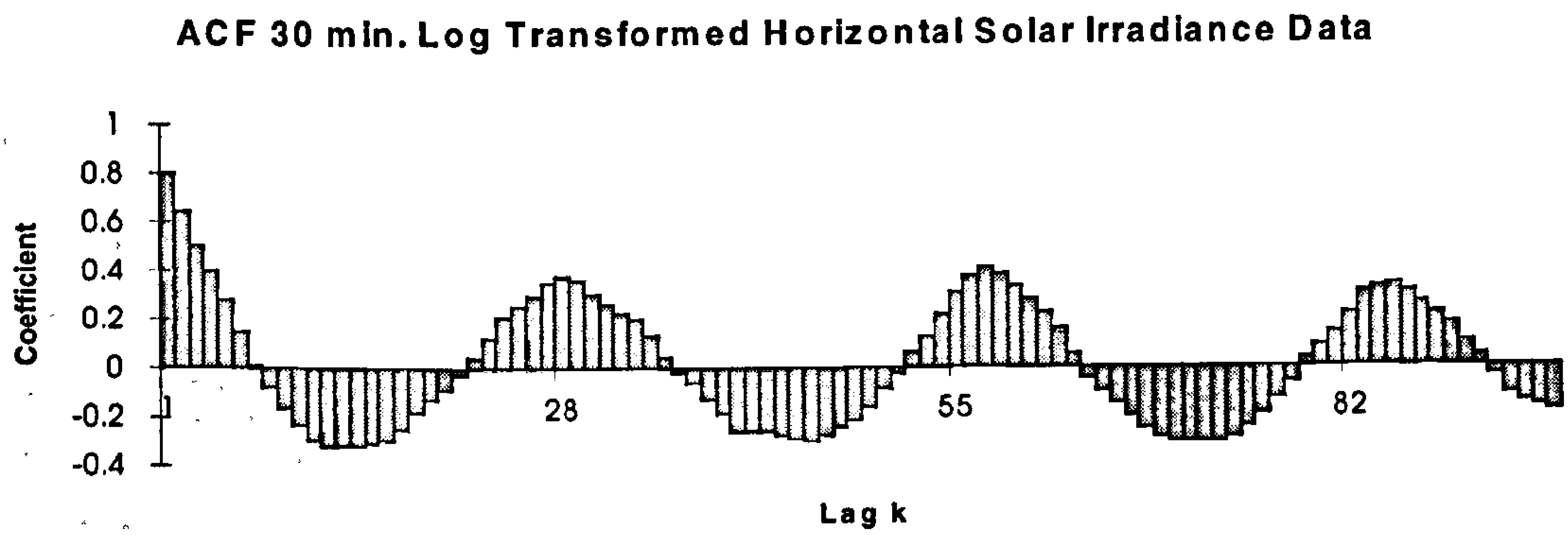


Figure 4.7.2 Log Transformed Horizontal Solar Irradiance - 30 minute averages, JUN94_30

a)



b)



c)

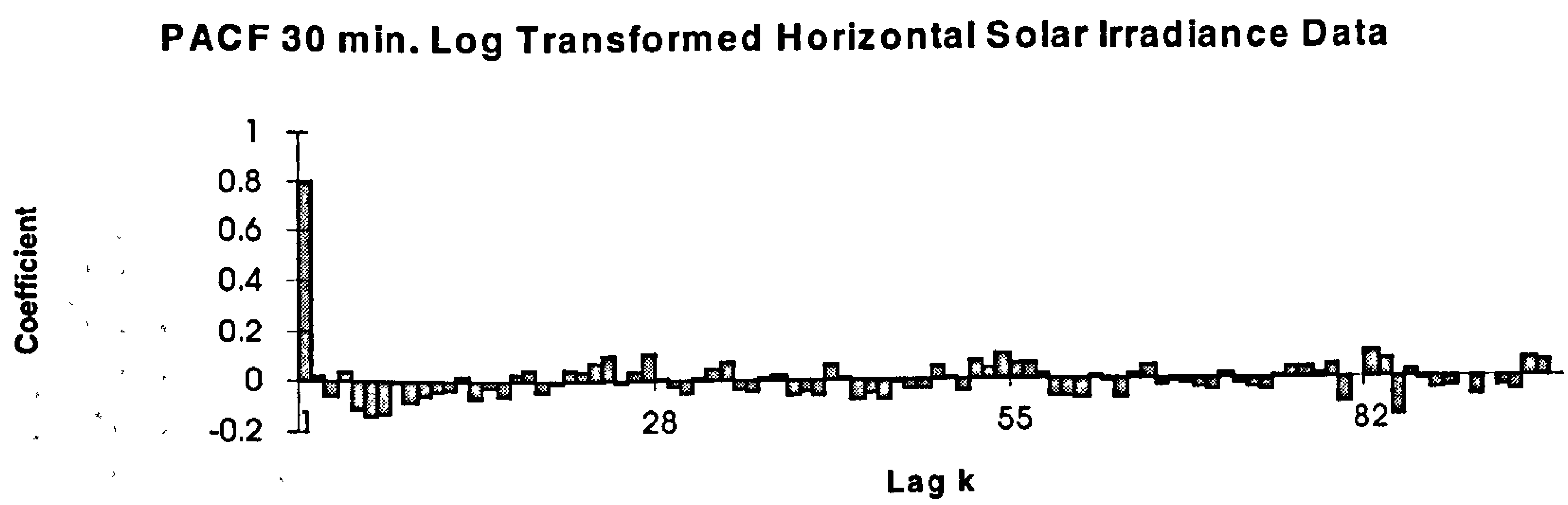
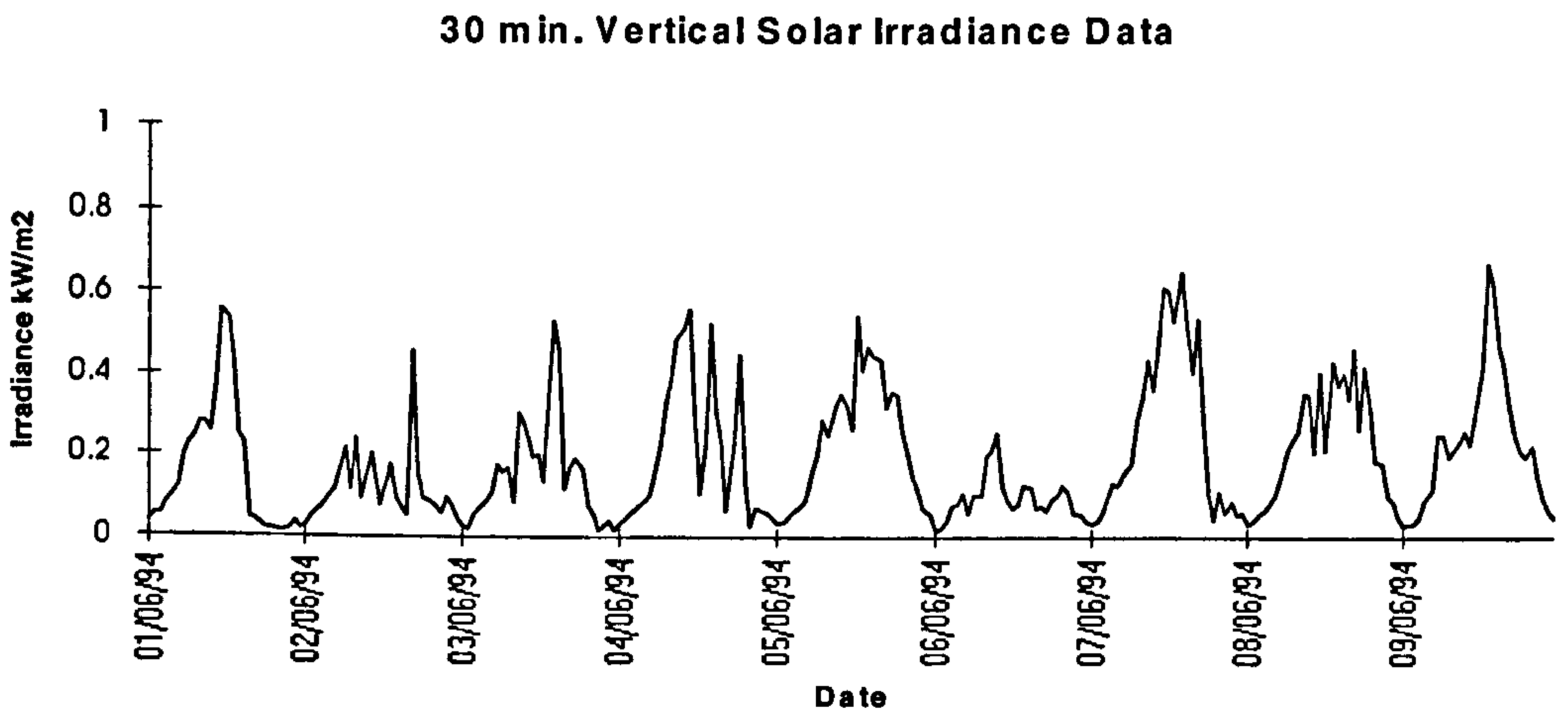
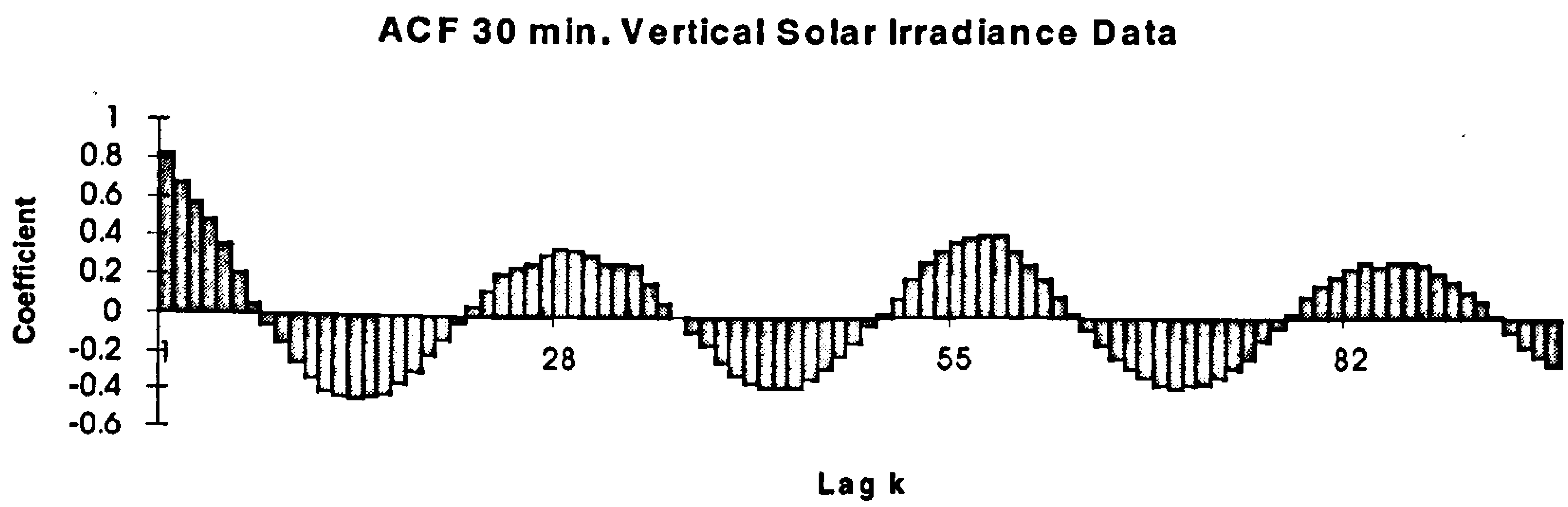


Figure 4.7.3 Vertical Solar Irradiance - 30 minute averages, JUN94_30

a)



b)



c)

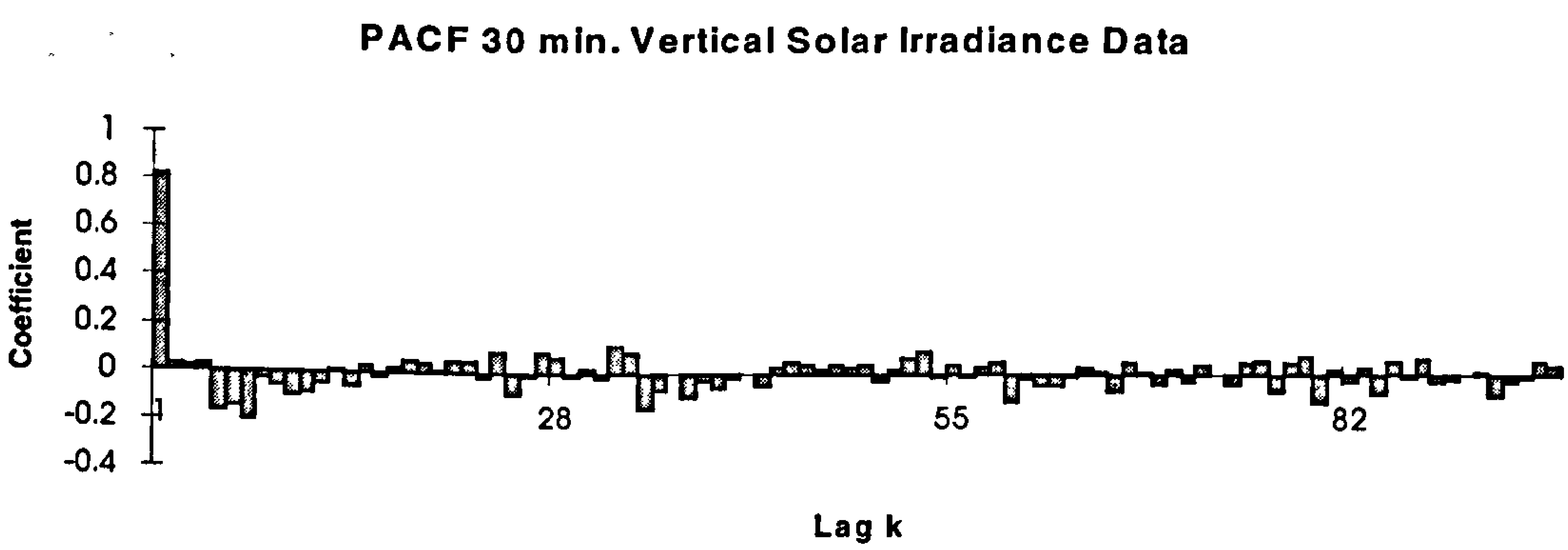
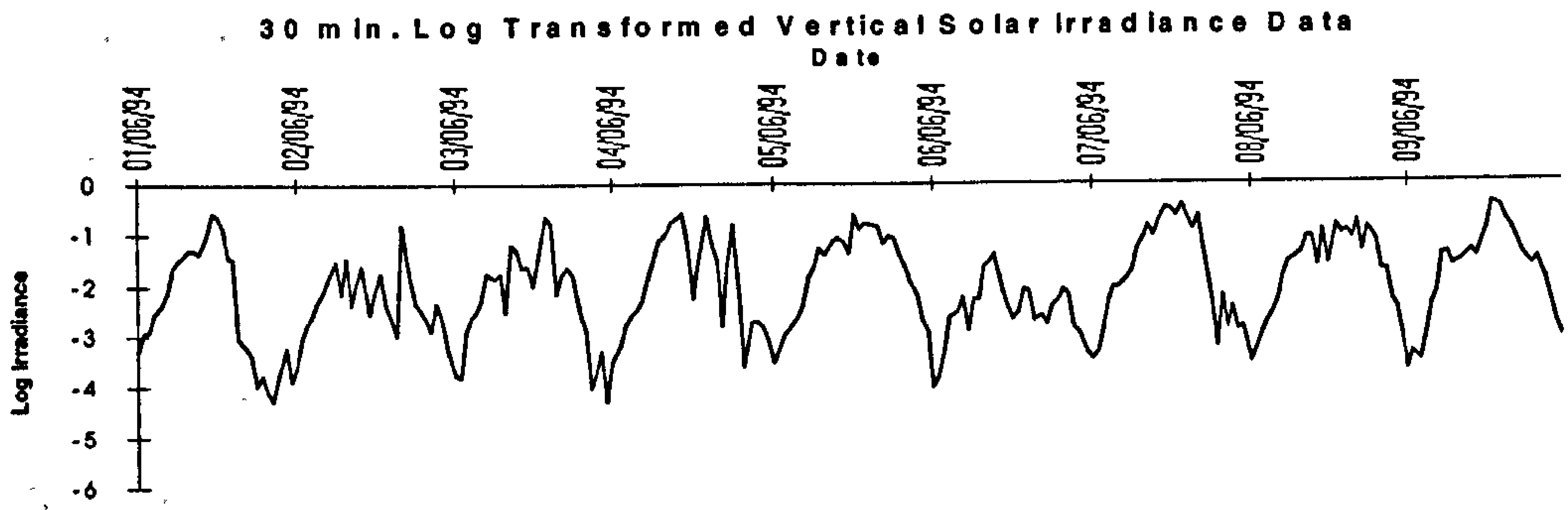
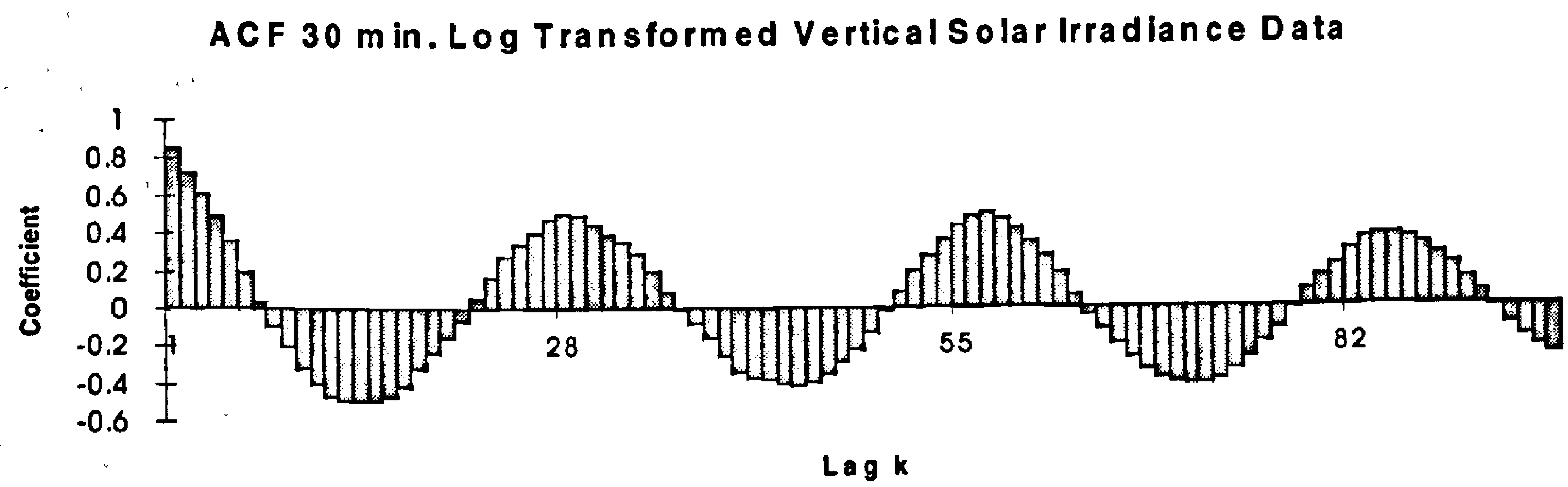


Figure 4.7.4 Log Transformed Vertical Solar Irradiance - 30 minute averages, JUN94_30

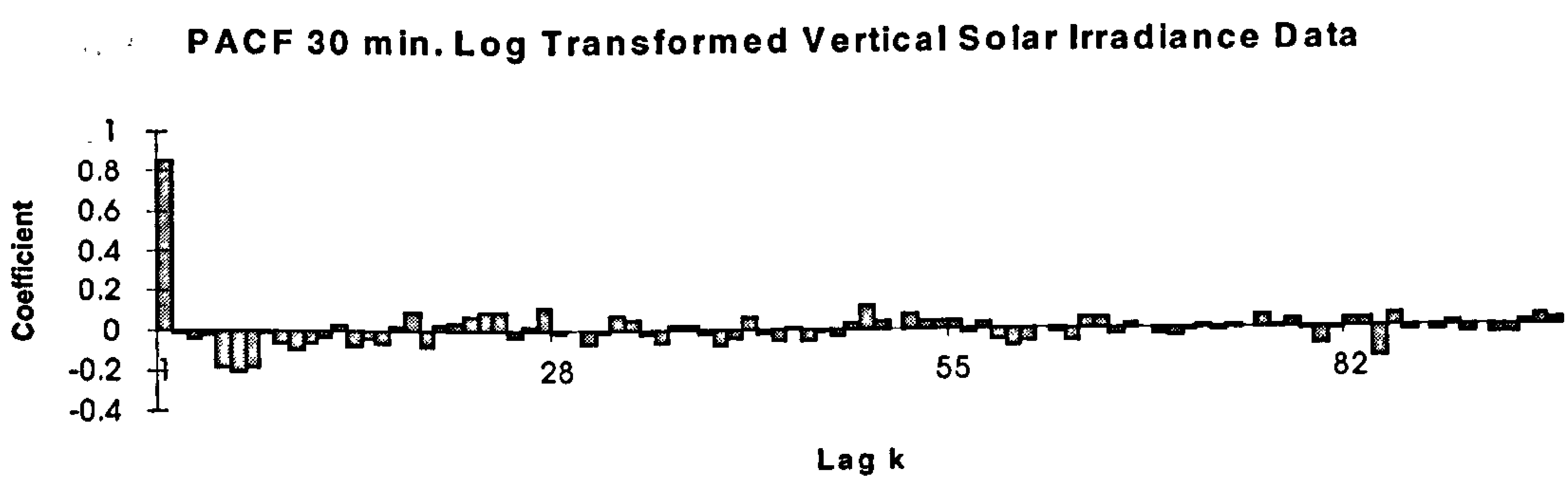
a)



b)



c)



4.8. June 1994 (1st - 9th) - Sixty minute averages

This data set, known as JUN94_60, contains 60 minute averaged Horizontal and Vertical Solar Irradiance data recorded between 1st and 9th June 1994.

4.8.1. Horizontal Solar Irradiance

The time series plot, Figure 4.8.1(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.8.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.8.1(b), and the structure of the ACF and PACF, Figure 4.8.1(b) & (c), an ARIMA(3,0,0) model was fitted to the data. This model accounted for 54% of the total variance but the ACF of the residuals had a significant value at lag14. An ARIMA(3,0,0)(1,0,0)14 model was then fitted to the data, this model accounted for 56% of the total variance and the ACF of the residuals showed no structure. It was found that an ARIMA(1,0,0)(1,0,0)14 model accounted for 60% of the total variance with no structure to the ACF of the residuals.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.8.1(b) an ARIMA(0,1,0)(1,0,0)14 model was fitted to the data. This model accounted for 46% of the total variance and the ACF of the residuals showed no structure.

4.8.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.8.2(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.8.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.8.2(b), and the structure of the ACF and PACF, Figure 4.8.2(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model to the data. This model accounted for 56% of the total variance and the ACF of the residuals showed no structure. An ARIMA(3,0,0)(1,0,0)14 model was also fitted to the data, this model also accounted for 56% of the variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.8.2(b) an ARIMA(0,1,0)(1,0,0)14 model was fitted to the data. This model accounted for 50% of the total variance, but the ACF of the residuals also had a significant value at lag 5.

4.8.3. Vertical Solar Irradiance

The time series plot, Figure 4.8.3(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.8.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.8.3(b), and the structure of the ACF and PACF, Figure 4.8.3(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model was found to be appropriate, accounted for 60% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.8.3(b) an ARIMA(0,1,0)(1,0,0)14 model was fitted to the

data. This model accounted for 53% of the total variance and the ACF of the residuals showed no structure.

4.8.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.8.4(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.8.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.8.4(b), and the structure of the ACF and PACF, Figure 4.8.4(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. However, the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.8.4(b) an ARIMA(0,1,0)(1,0,0)14 model was fitted to the data. This model accounted for 64% of the total variance and the ACF of the residuals showed no structure.

Table 4.8.1 Summary information for Horizontal Solar Irradiance - 60 minute averages (datafile JUN94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.3552	0.2082	0.0386	0.8048

b)

$2/\sqrt{126}=0.178$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.708	0.708	-0.127	-0.127
2	0.494	-0.014	0.132	0.118
3	0.214	-0.262	-0.087	-0.059
4	-0.013	-0.143	-0.040	-0.074
14	0.342	0.122	0.230	0.064

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)14	AR1	0.7227	0.0627	11.53	1.09671	0.00892	60
	SAR14	0.3218	0.0914	3.52			
	CONST	0.0347	0.0084	4.13			
ARIMA(3,0,0)	AR1	0.7267	0.0870	8.35	2.44342	0.02003	54
	AR2	0.1860	0.1075	1.73			
	AR3	-0.2822	0.0869	-3.25			
	CONST	0.1295	0.0126	10.26			
ARIMA(3,0,0)(1,0,0)14	AR1	0.6898	0.0888	7.77	2.2686	0.01875	56
	AR2	0.1704	0.1067	1.60			
	AR3	-0.2382	0.0883	-2.70			
	SAR14	0.3018	0.0958	3.15			
	CONST	0.0927	0.0122	7.59			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.2960	0.0943	3.14	2.8666	0.02312	46

Table 4.8.2 Summary information for Log Transformed Horizontal Solar Irradiance - 60 minute averages (datafile JUN94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.2612	0.7463	-3.2536	-0.2171

b)

2/√126=0.178	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.714	0.714	0.005	0.005
2	0.433	-0.158	-0.002	-0.002
3	0.160	-0.179	-0.058	-0.058
4	-0.079	-0.160	-0.075	-0.074
14	0.396	0.084	0.215	0.027

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)14	AR1	0.6882	0.0658	10.45	2.39841	0.01950	55
	SAR14	0.3410	0.0927	3.68			
	CONST	0.0720	0.0125	5.78			
ARIMA(3,0,0)	AR1	0.8117	0.0889	9.13	31.4301	0.2576	54
	AR2	-0.0073	0.1152	-0.06			
	AR3	-0.1938	0.0889	-2.17			
	CONST	-0.4959	0.0452	-10.97			
ARIMA(3,0,0)(1,0,0)14	AR1	0.7456	0.0910	8.19	29.4574	0.2434	56
	AR2	-0.0051	0.1120	-0.05			
	AR3	-0.1471	0.002	-1.63			
	SAR14	0.2799	0.0944	2.96			
	CONST	-0.3745	0.0439	-8.52			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.2674	0.0925	2.89	36.6192	0.2953	50

Table 4.8.3 Summary information for Vertical Solar Irradiance - 60 minute averages (datafile JUN94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1889	0.1495	0.0185	0.5798

b)

$2/\sqrt{126}=0.178$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.749	0.749	-0.036	-0.036
2	0.520	-0.094	0.147	0.146
3	0.225	-0.300	-0.025	-0.015
4	-0.051	-0.211	-0.088	-0.113
14	0.383	0.112	0.209	-0.008

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)14	AR1	0.6717	0.0677	9.92	30.2657	0.2461	56
	SAR14	0.3439	0.0905	3.80			
	CONST	-0.2766	0.0442	-6.25			
ARIMA(4,0,0)	AR1	0.7315	0.0887	8.25	1.01622	0.00840	62
	AR2	0.1993	0.1101	1.81			
	AR3	-0.1385	0.1101	-1.26			
	AR4	-0.2232	0.0888	-2.51			
	CONST	0.08077	0.00817	9.89			
ARIMA(0,1,0)(1,0,0)	SAR14	0.2383	0.0935	2.55	1.2969	0.01046	53

Table 4.8.4 Summary information for Log Transformed Vertical Solar Irradiance - 60 minute averages (datafile JUN94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0188	0.8972	-3.9900	-0.5450

b)

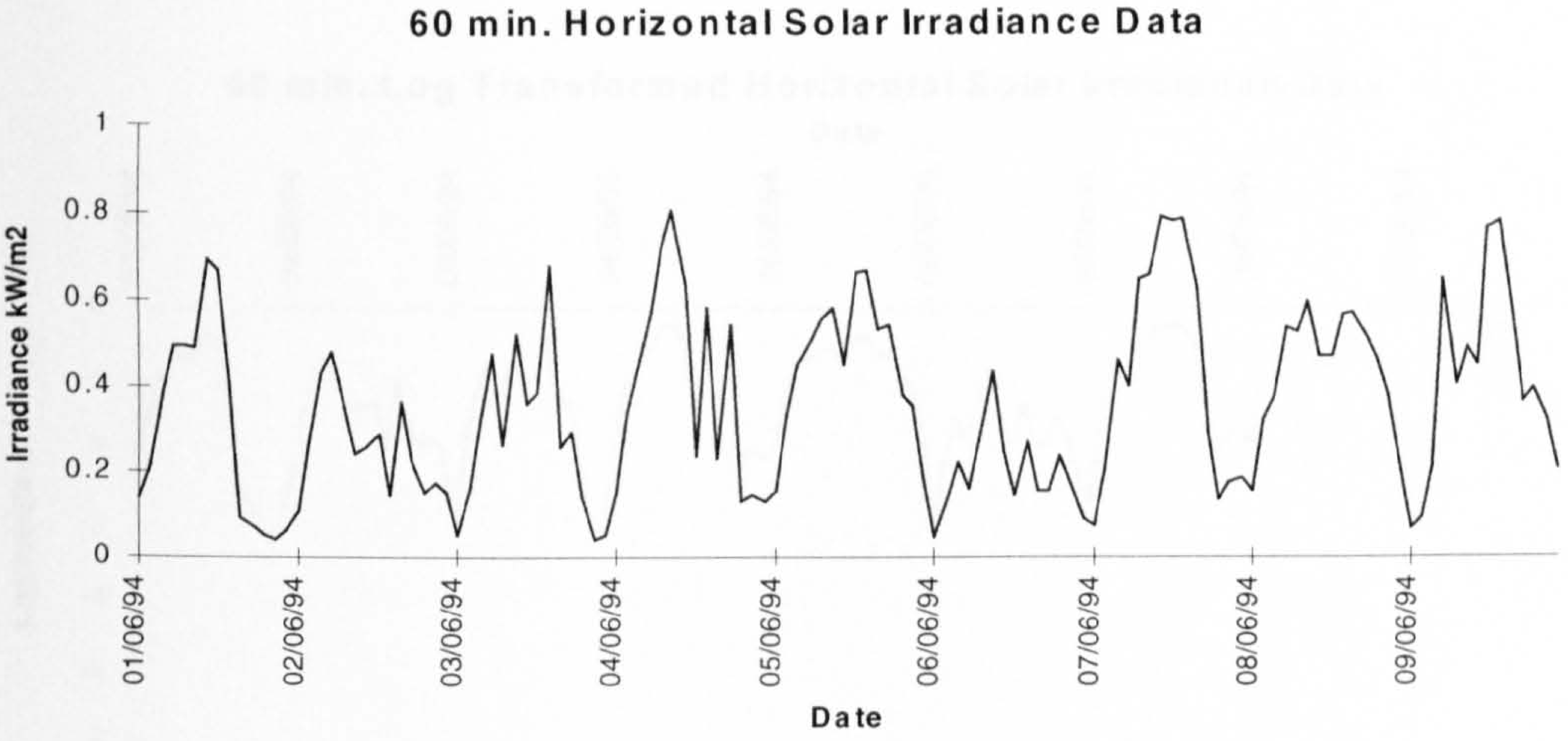
$2/\sqrt{126}=0.178$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.784	0.784	0.139	0.139
2	0.521	-0.242	0.146	0.129
3	0.208	-0.362	0.015	-0.021
4	-0.104	-0.246	-0.144	-0.168
14	0.527	0.060	0.316	0.069

c)

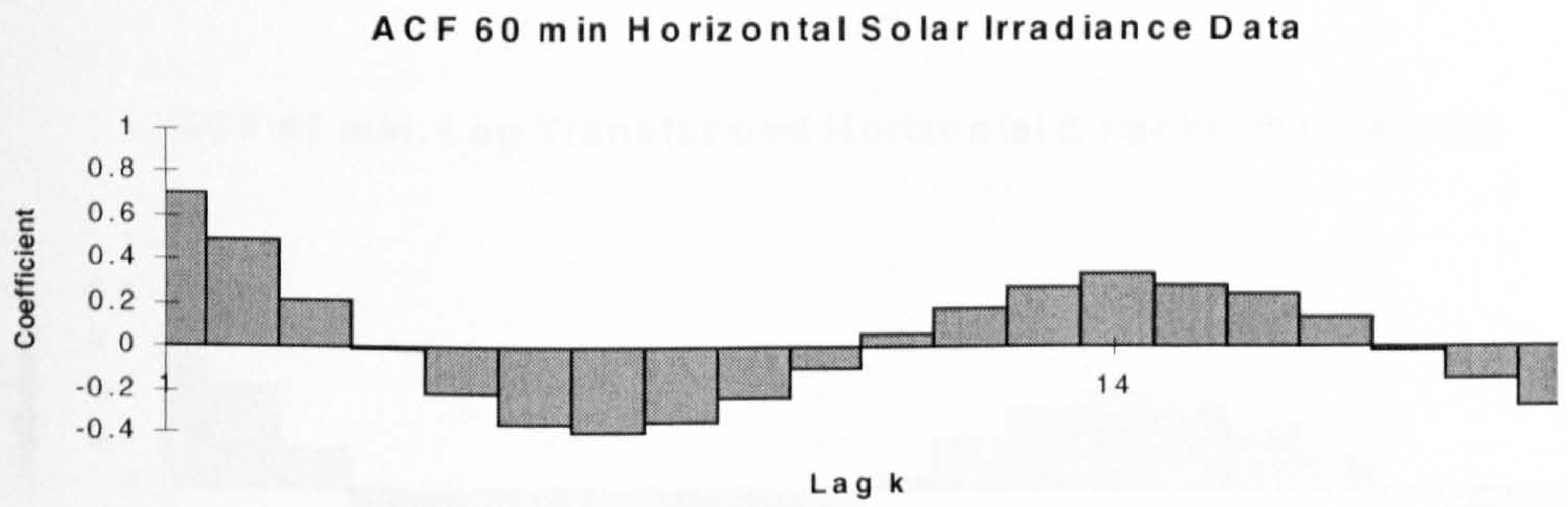
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)14	AR1	0.7249	0.0634	11.43	30.2699	0.2461	69
	SAR14	0.4807	0.0838	5.73			
	CONST	-0.2944	0.0443	-6.65			
ARIMA(4,0,0)	AR1	0.8443	0.0881	9.58	28.6794	0.2370	70
	AR2	0.0709	0.1160	0.68			
	AR3	-0.0904	0.1162	-0.78			
	AR4	-0.2679	0.0881	-3.04			
	CONST	-0.8880	0.0434	-20.47			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.4086	0.0866	4.72	35.4821	0.2861	64

Figure 4.8.1 Horizontal Solar Irradiance - 60 minute averages, JUN94_60

a)



b)



c)

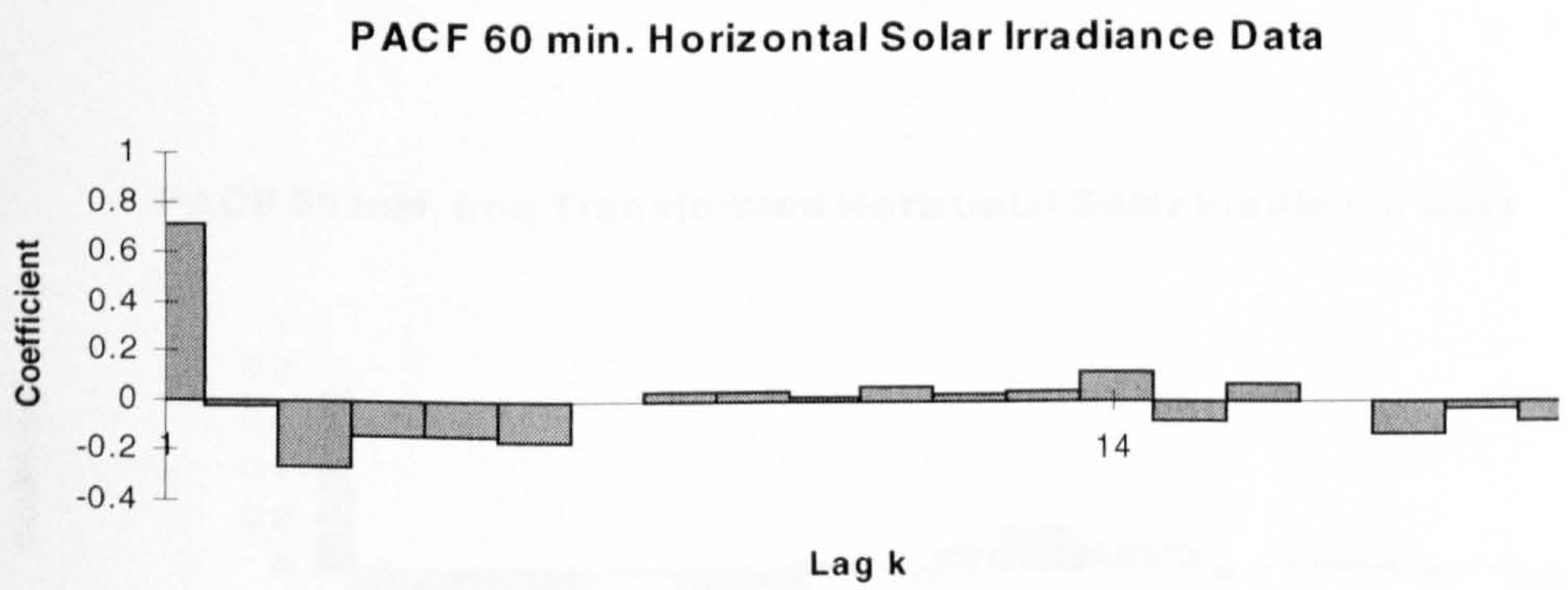
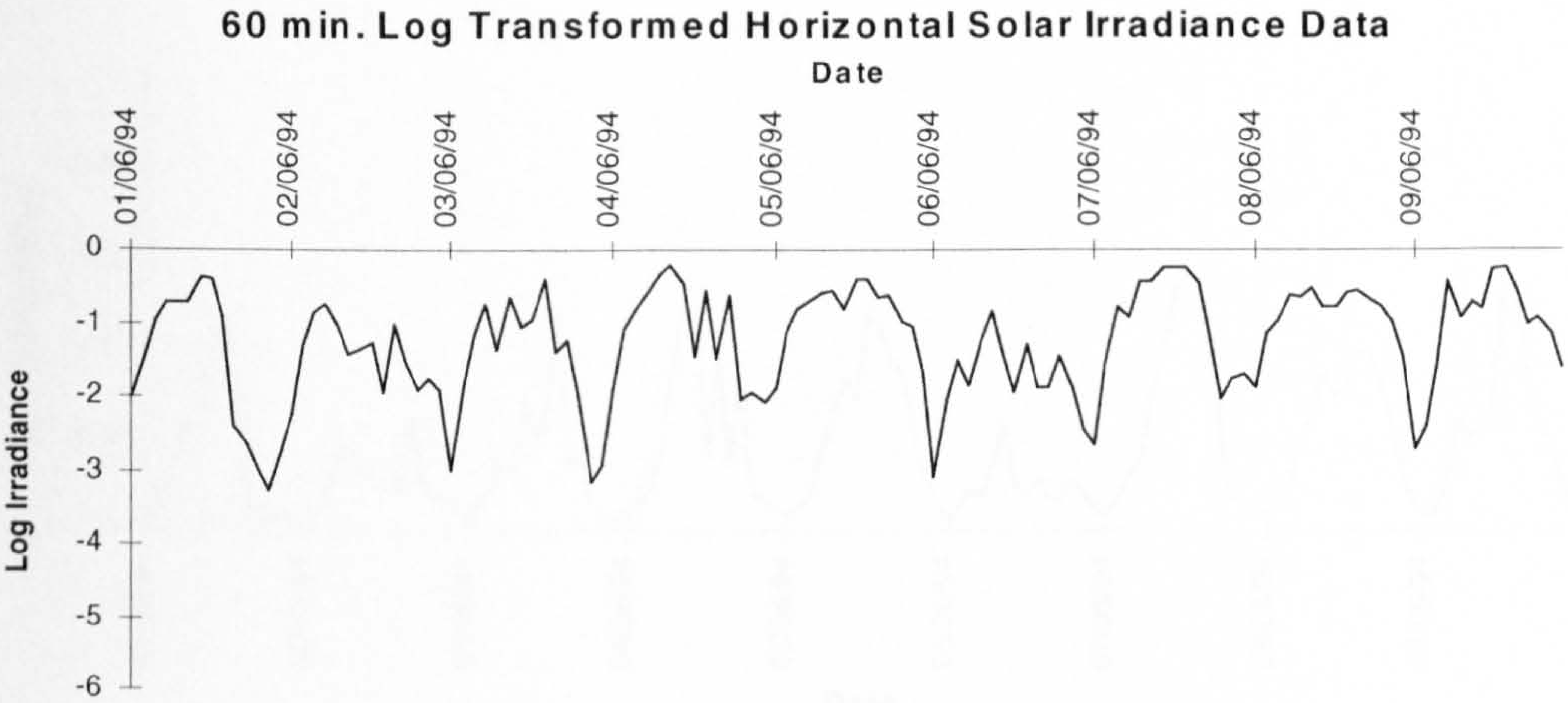
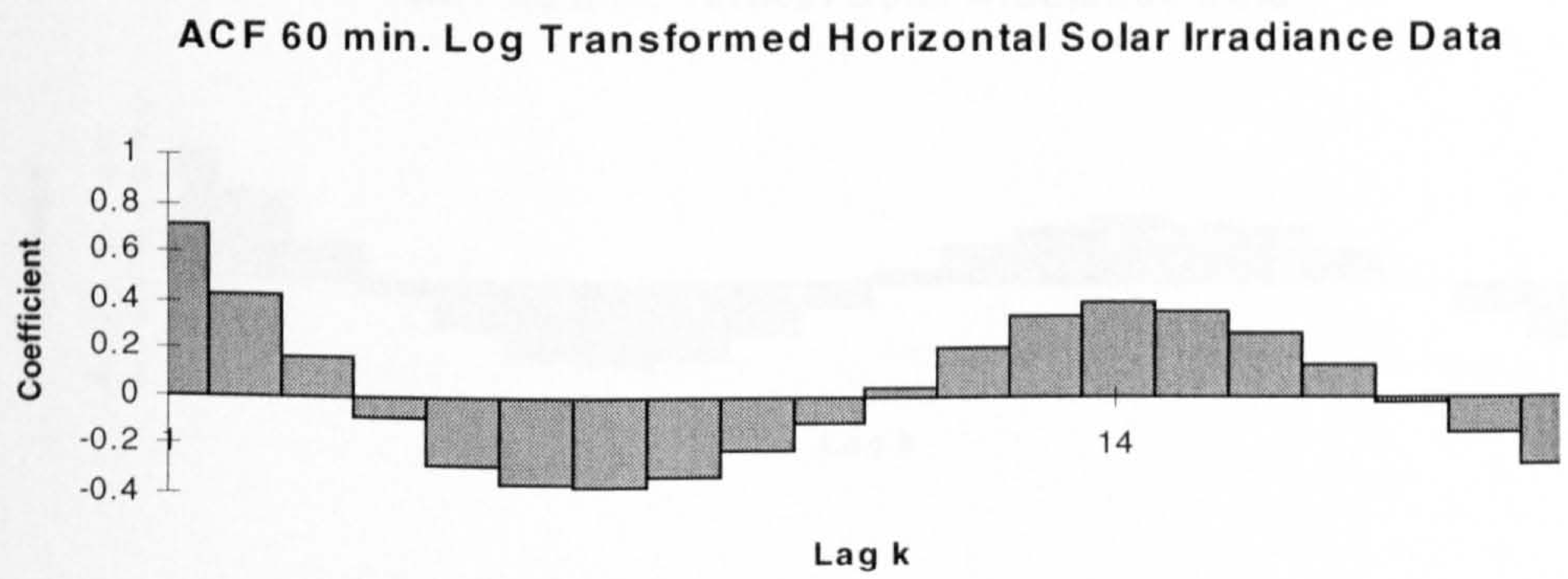


Figure 4.8.2 Log transformed Horizontal Solar Irradiance - 60 minute averages, JUN94_60

a)



b)



c)

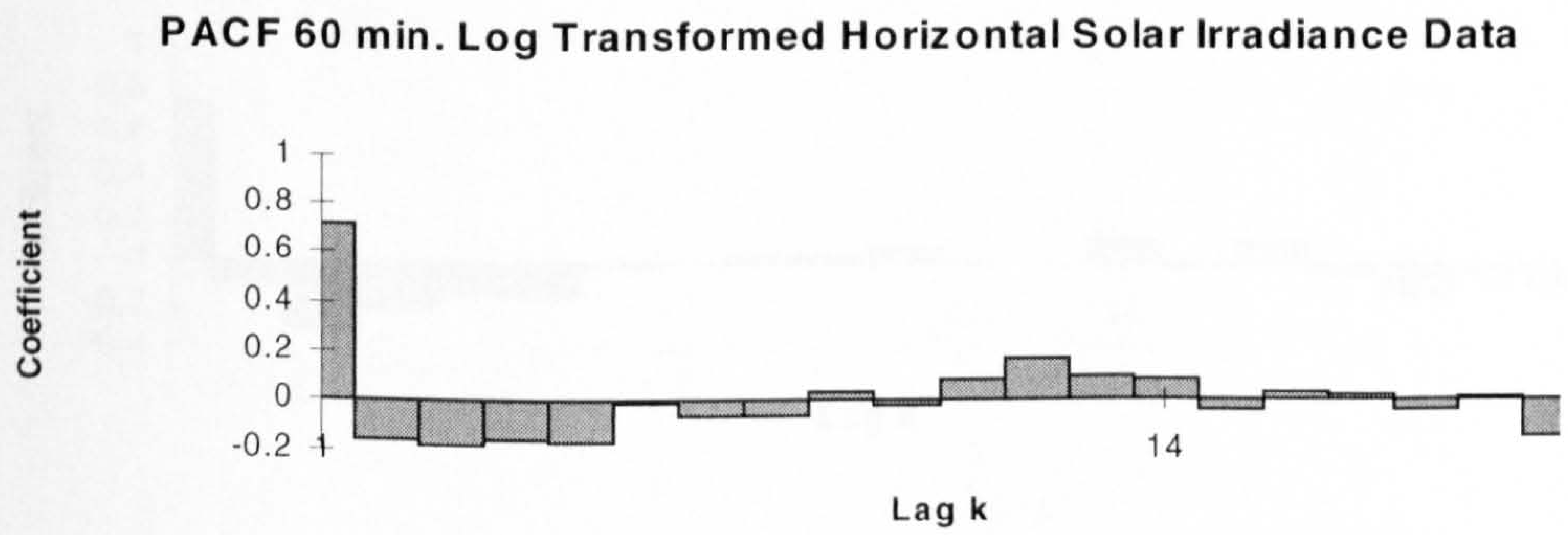
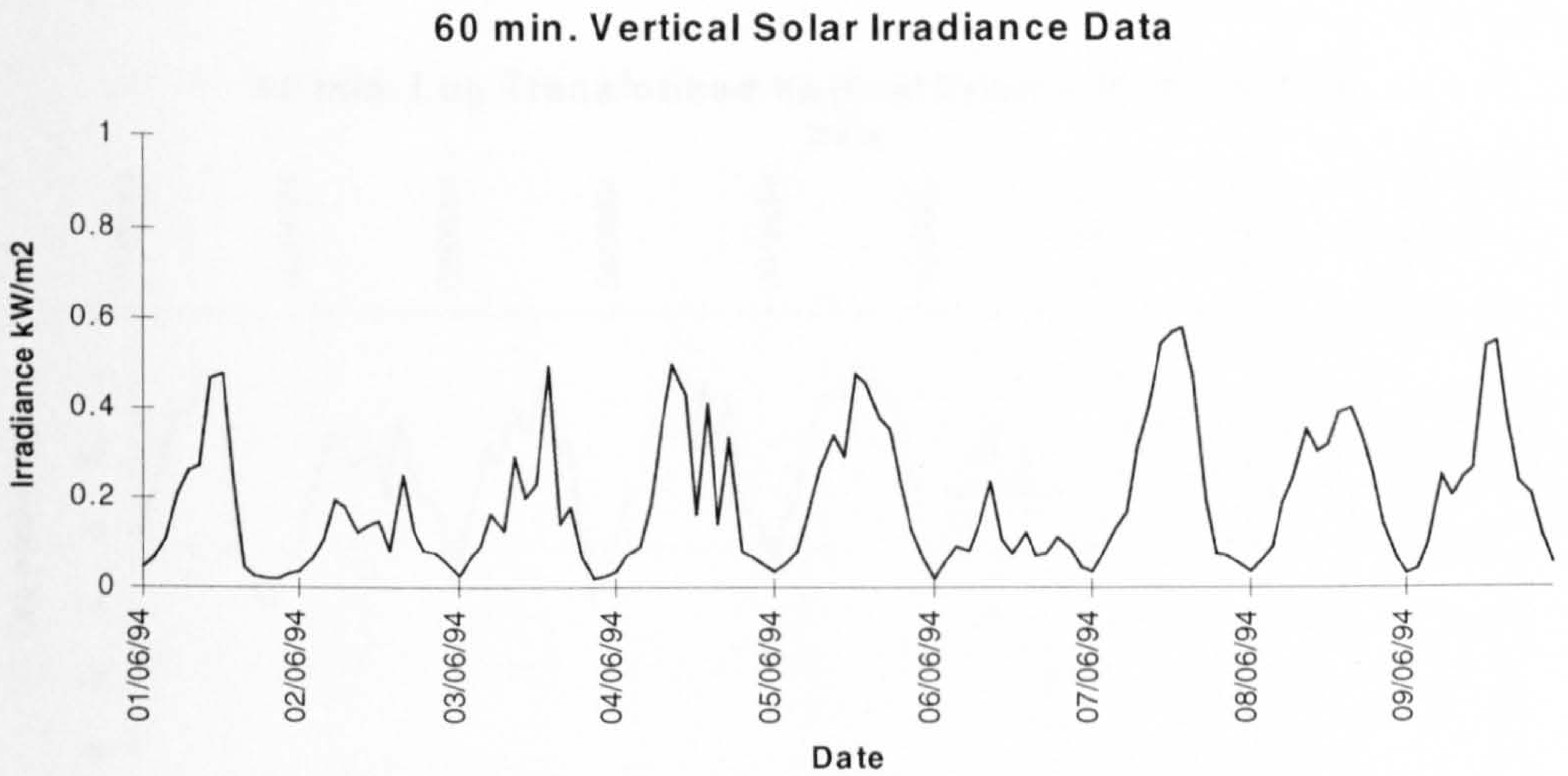
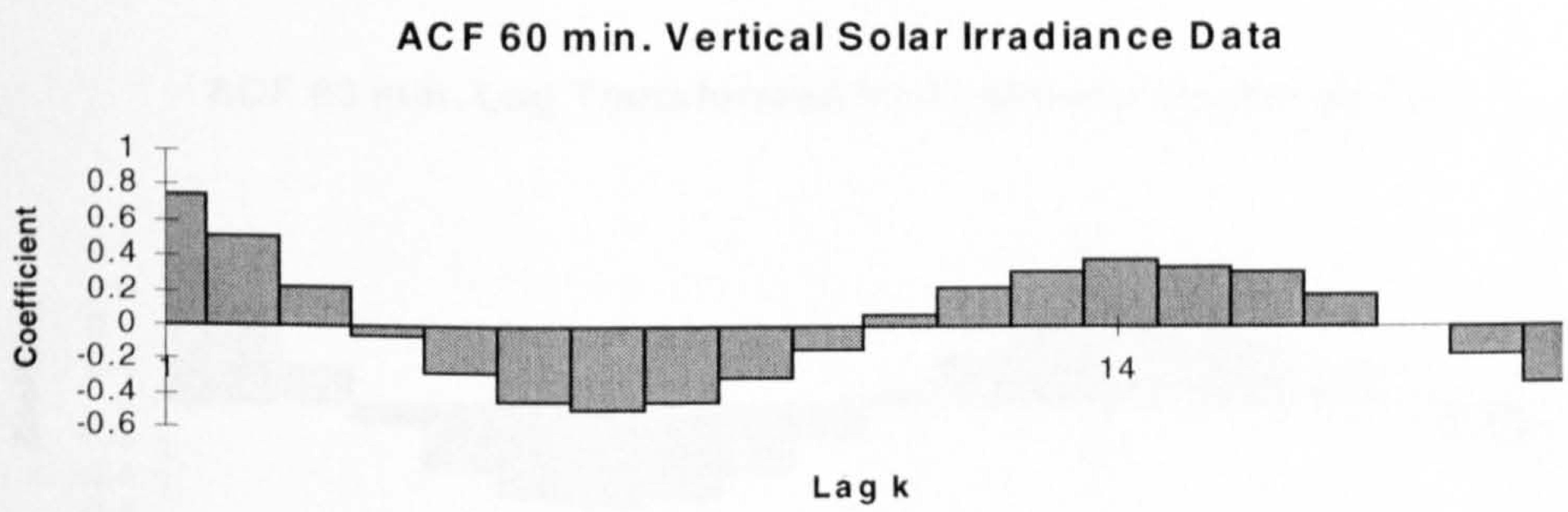


Figure 4.8.3 Vertical Solar Irradiance - 60 minute averages, JUN94_60

a)



b)



c)

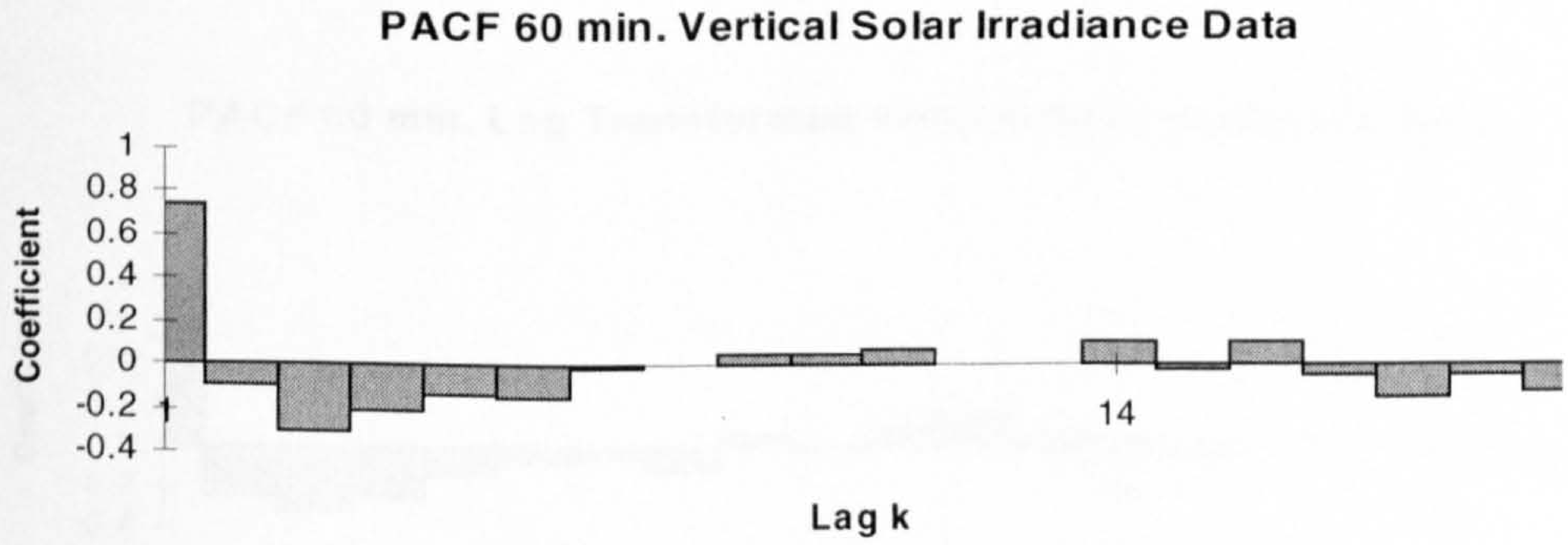
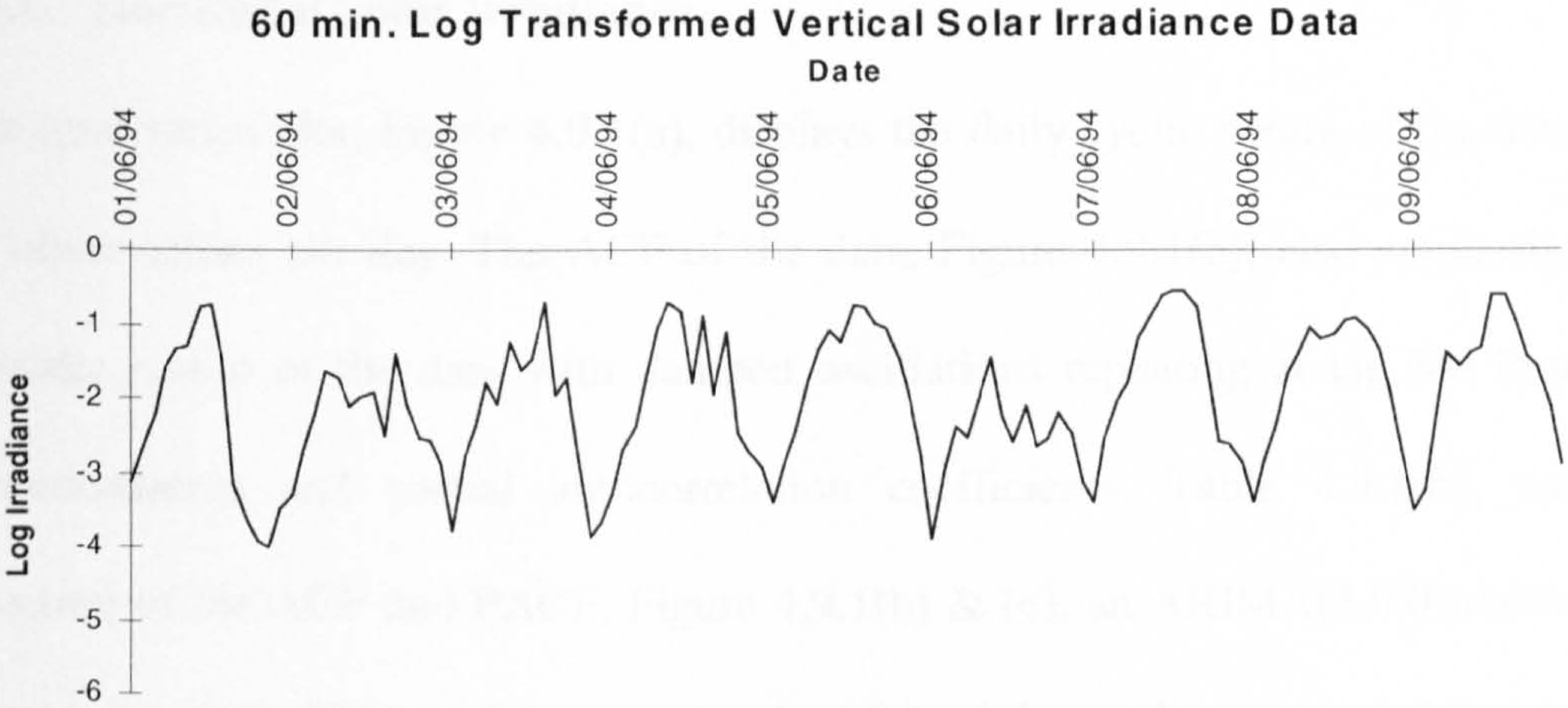
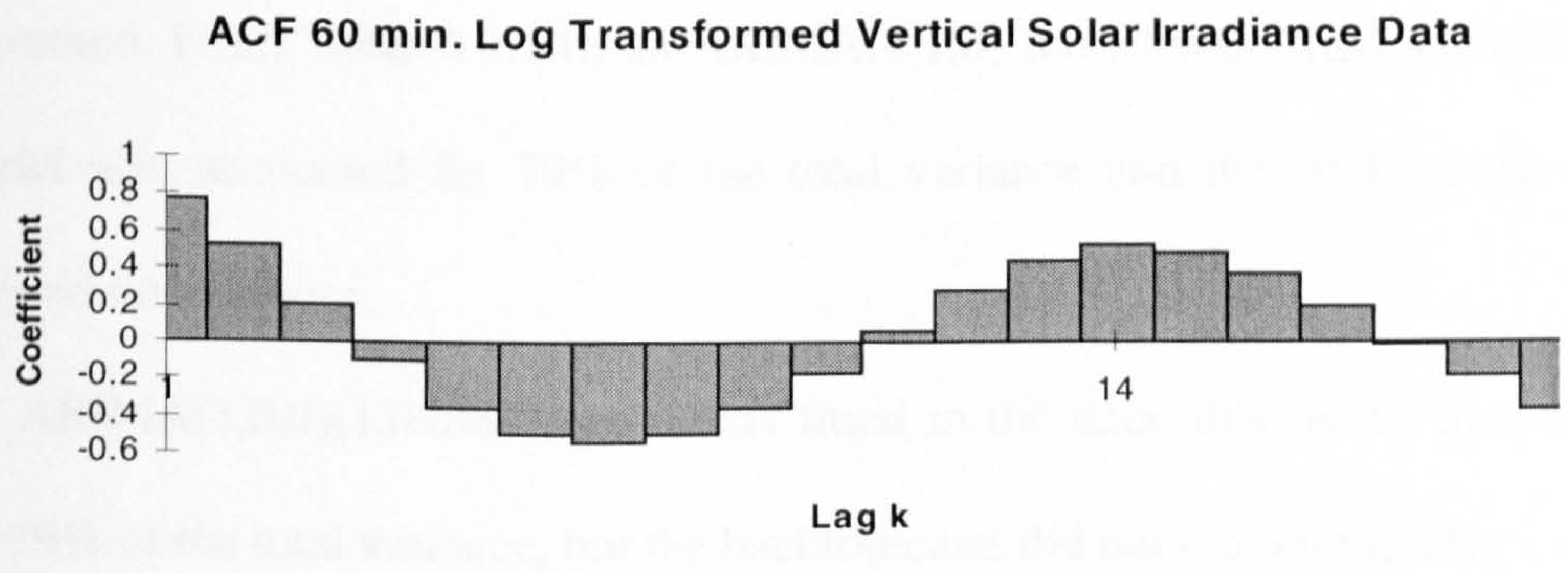


Figure 4.8.4 Log transformed Vertical Solar Irradiance - 60 minute averages, JUN94_60

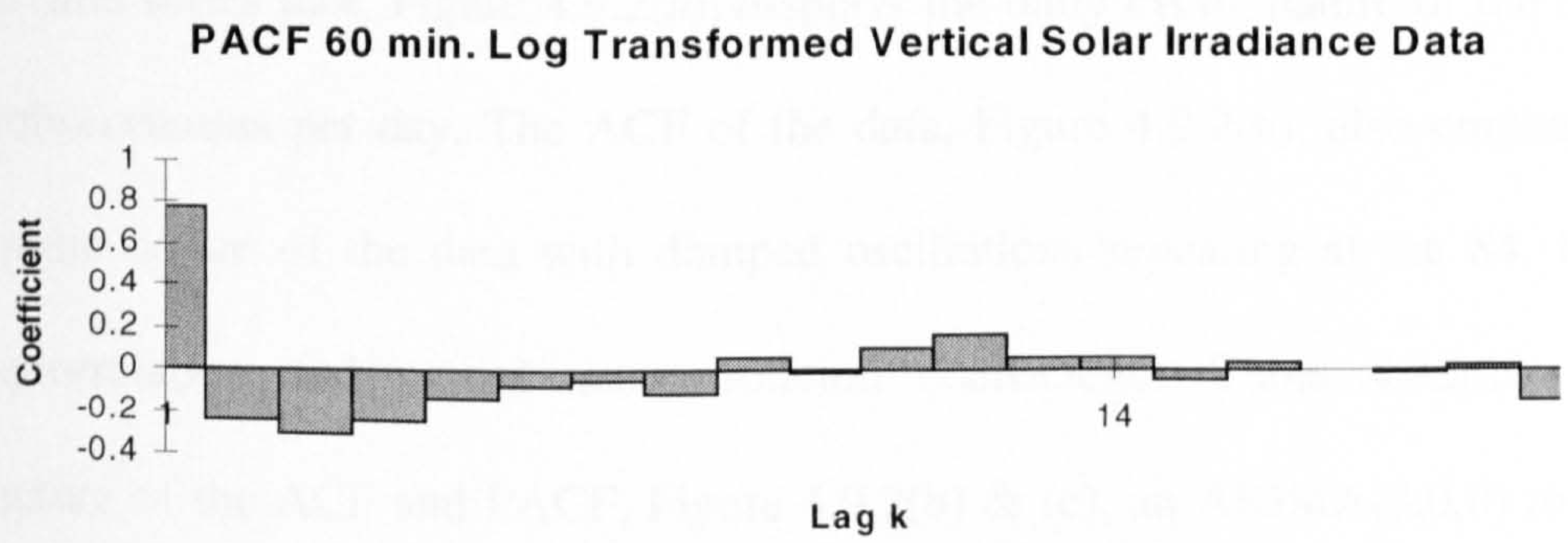
a)



b)



c)



4.9. June 1994 (18th - 30th) - Ten minute averages

This data set, known as JUN94_10(18th-30th), contains 10 minute averaged Solar Irradiance data recorded between 18th and 30th June 1994.

4.9.1. Horizontal Solar Irradiance

The time series plot, Figure 4.9.1(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.9.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.9.1(b), and the structure of the ACF and PACF, Figure 4.9.1(b) & (c), an ARIMA(3,0,0) model was fitted to the data. This model accounted for 79% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.9.1(b) an ARIMA(4,1,0) model was fitted to the data. This model also accounted for 79% of the total variance and the ACF of the residuals showed no structure.

An ARIMA(3,0,0)(1,0,0)84 model was fitted to the data, this model also accounted for 79% of the total variance, but the backforecasts did not die out rapidly.

4.9.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.9.2(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.9.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.9.2(b), and the structure of the ACF and PACF, Figure 4.9.2(b) & (c), an ARIMA(3,0,0) model was

fitted to the data. This model accounted for 85% of the total variance but the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.9.2(b) an ARIMA(3,1,0) model was fitted to the data. This model also accounted for 85% of the total variance but the ACF of the residuals had a significant value at lag 84. An ARIMA(3,1,0)(1,0,0)84 model was then fitted to the data, accounted for 85% of the total variance and the ACF of the residuals showed no structure.

4.9.3. Vertical Solar Irradiance

The time series plot, Figure 4.9.3(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.9.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.9.3(b), and the structure of the ACF and PACF, Figure 4.9.3(b) & (c), an ARIMA(3,0,0) model to the data. This model accounted for 84% of the total variance but the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.9.3(b) an ARIMA(4,1,0) model was fitted to the data. This model also accounted for 84% of the total variance and the ACF of the residuals showed no structure.

4.9.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.9.4(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.9.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.9.4(b), and the structure of the ACF and PACF, Figure 4.9.4(b) & (c), an ARIMA(1,0,0) model was fitted to the data. However, the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.9.4(b) an ARIMA(2,1,0) model was fitted to the data, this model accounted for 91% of the total variance and the ACF of the residuals showed no structure.

Table 4.9.1 Summary information for Horizontal Solar Irradiance - 10 minute averages (datafile JUN94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.3609	0.2537	0.0139	1.0220

b)

$2/\sqrt{1092} = 0.060$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.881	0.881	-0.223	-0.223
2	0.814	0.172	-0.121	-0.180
3	0.776	0.144	-0.005	-0.083
4	0.739	0.055	-0.05	-0.105
84	0.248	0.008	0.014	0.019

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1	0.7039	0.0300	23.47	14.8274	0.0136	79
	AR2	0.0679	0.0367	1.85			
	AR3	0.1461	0.0300	4.87			
	CONST	0.0289	0.0035	8.20			
ARIMA(3,0,0)(1,0,0)84	AR1	0.7038	0.0300	23.45	14.8148	0.0136	79
	AR2	0.0650	0.0368	1.76			
	AR3	0.1482	0.0300	4.94			
	SAR84	0.0312	0.0320	0.97			
	CONST	0.0286	0.0035	8.08			
ARIMA(4,1,0)	AR1	-0.2869	0.0302	-9.51	14.9983	0.0138	79
	AR2	-0.2234	0.0312	-7.16			
	AR3	-0.1128	0.0312	-3.61			
	AR4	-0.1052	0.0302	-3.49			

Table 4.9.2 Summary information for Log Transformed Horizontal Solar Irradiance - 10 minute averages (datafile JUN94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.3341	0.8818	-4.2759	0.0218

b)

$2/\sqrt{1092} = 0.060$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.921	0.921	-0.075	-0.075
2	0.852	0.029	-0.088	-0.094
3	0.798	0.058	-0.053	-0.069
4	0.753	0.05	0.031	0.013
84	0.350	0.015	0.075	0.046

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.9279	0.0115	80.76	122.786	0.113	85
	CONST	-0.0987	0.0102	-9.71			
ARIMA(3,1,0)	AR1	-0.0882	0.0302	-2.91	125.439	0.115	85
	AR2	-0.1000	0.0302	-3.31			
	AR3	-0.0689	0.0303	-2.28			
ARIMA(3,1,0)(1,0,0)84	AR1	-0.0911	0.0302	-3.01	124.317	0.114	85
	AR2	-0.1093	0.0303	-3.61			
	AR3	-0.0791	0.0303	-2.61			
	SAR84	0.0988	0.0313	3.16			

Table 4.9.3 Summary information for Vertical Solar Irradiance - 10 minute averages (datafile JUN94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2002	0.1757	0.0069	0.7247

b)

$2/\sqrt{1092} = 0.060$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.910	0.910	-0.203	-0.203
2	0.857	0.163	-0.124	-0.172
3	0.825	0.143	-0.005	-0.074
4	0.794	0.052	-0.077	-0.126
84	0.300	0.001	-0.011	0.001

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1	0.7372	0.0300	24.58	5.43261	0.00499	84
	AR2	0.0551	0.0374	1.48			
	AR3	0.1456	0.0300	4.86			
	CONST	0.0120	0.0021	5.63			
ARIMA(4,1,0)	AR1	-0.2595	0.0301	-8.62	5.43944	0.00500	84
	AR2	-0.2132	0.0309	-6.89			
	AR3	-0.1055	0.0309	-3.41			
	AR4	-0.1257	0.0301	-4.18			
ARIMA(4,1,0)(1,0,0)84	AR1	-0.2603	0.0301	-8.65	5.4374	0.00501	83
	AR2	-0.2161	0.0311	-6.94			
	AR3	-0.1079	0.0310	-3.48			
	AR4	-0.1275	0.0303	-4.21			
	SAR84	0.0209	0.0325	0.64			

Table 4.9.4 Summary information for Log Transformed Vertical Solar Irradiance - 10 minute averages (datafile JUN94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0400	0.9935	-4.9762	-0.3220

b)

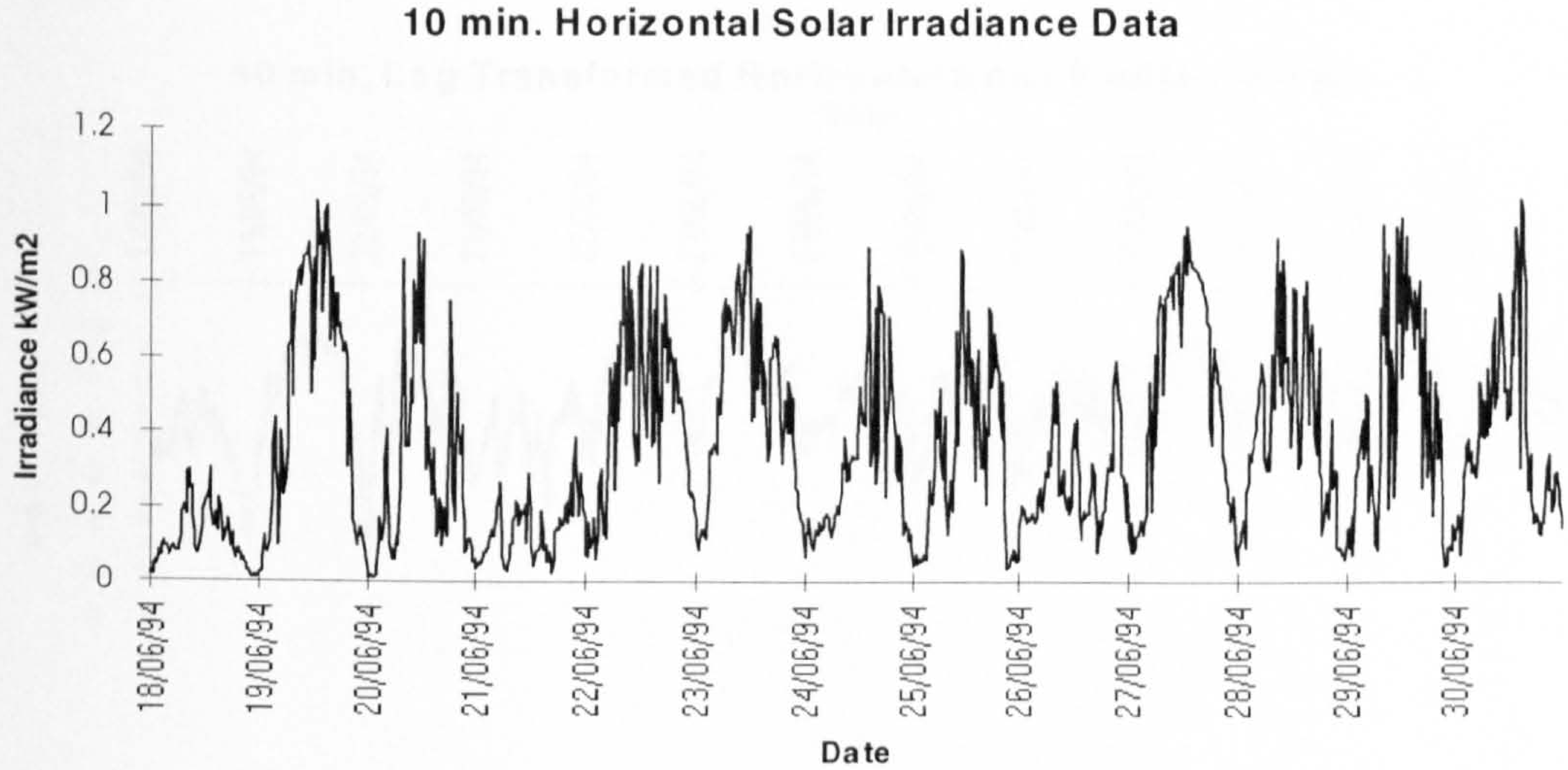
$2/\sqrt{1092} = 0.060$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.952	0.952	-0.007	-0.007
2	0.904	-0.016	-0.08	-0.08
3	0.865	0.0058	-0.013	-0.014
4	0.828	0.011	0.032	0.025
84	0.425	-0.001	0.035	0.041

c)

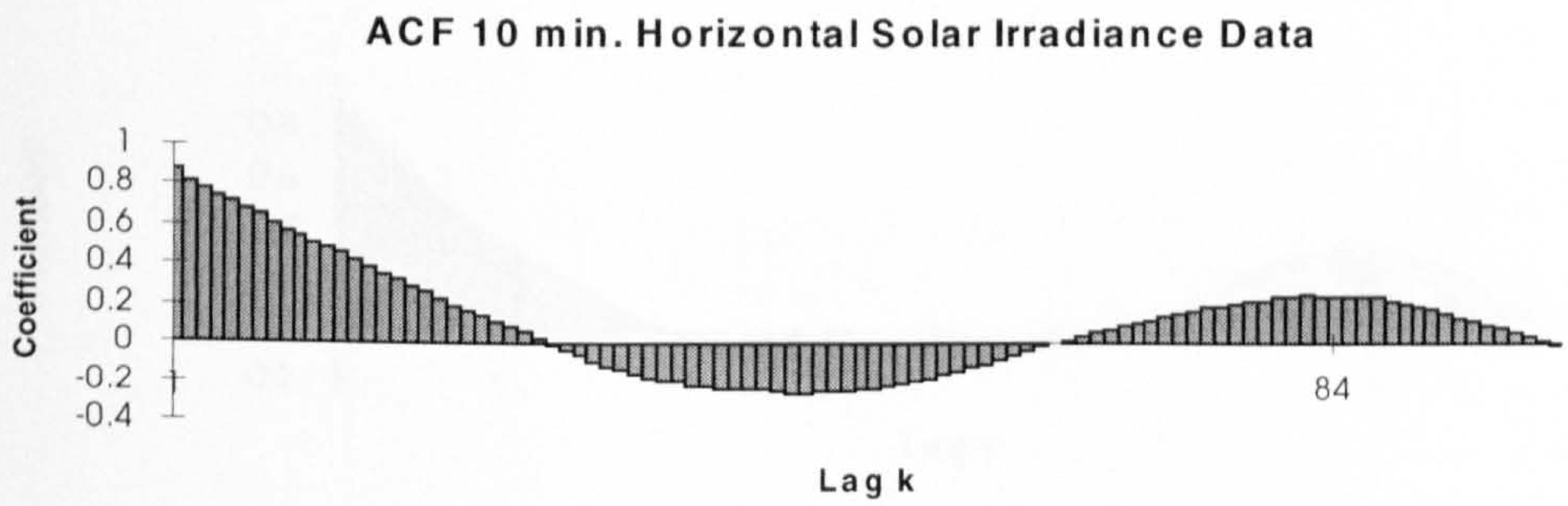
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.9579	0.0090	106.7	94.9442	0.0871	91
	CONST	-0.0888	0.0089	-9.92			
ARIMA(2,1,0)	AR1	-0.0079	0.0302	-0.26	96.6382	0.0887	91
	AR2	-0.0800	0.0302	-2.65			
ARIMA(2,1,0)(1,0,0)84	AR1	-0.0127	0.0302	-0.42	96.4162	0.0886	91
	AR2	-0.0861	0.0303	-2.84			
	SAR84	0.0504	0.0315	1.60			

Figure 4.9.1 Horizontal Solar Irradiance - 10 minute averages, JUN94_10

a)



b)



c)

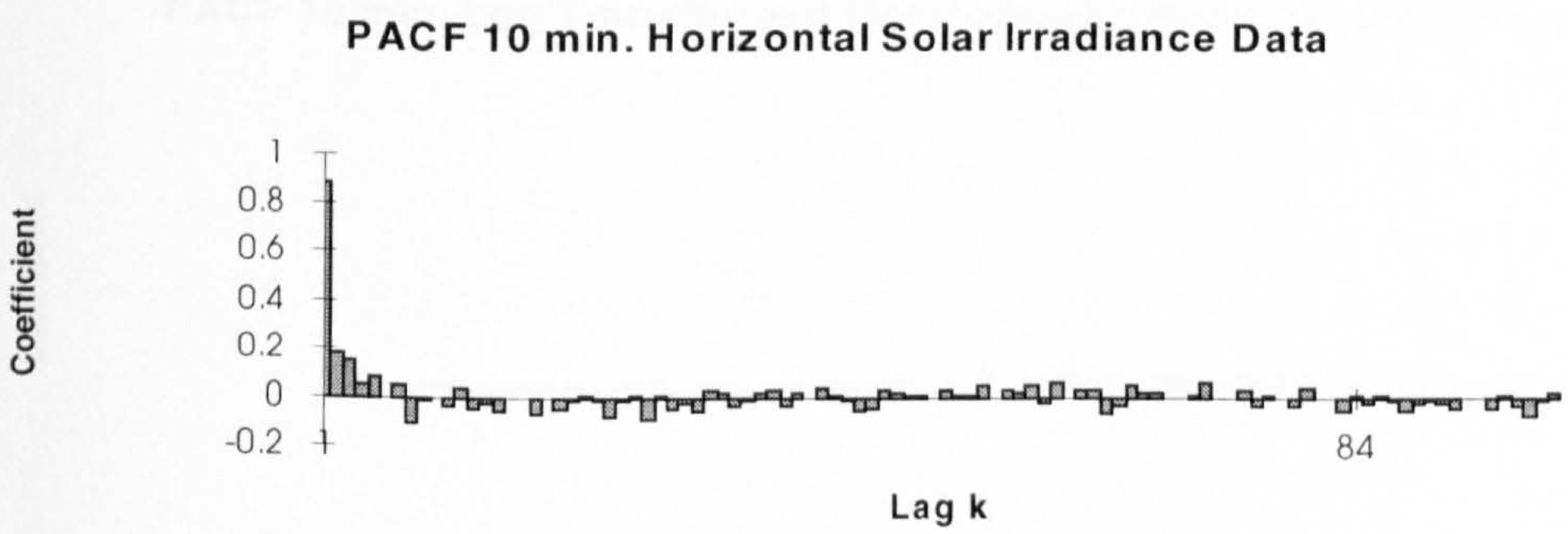
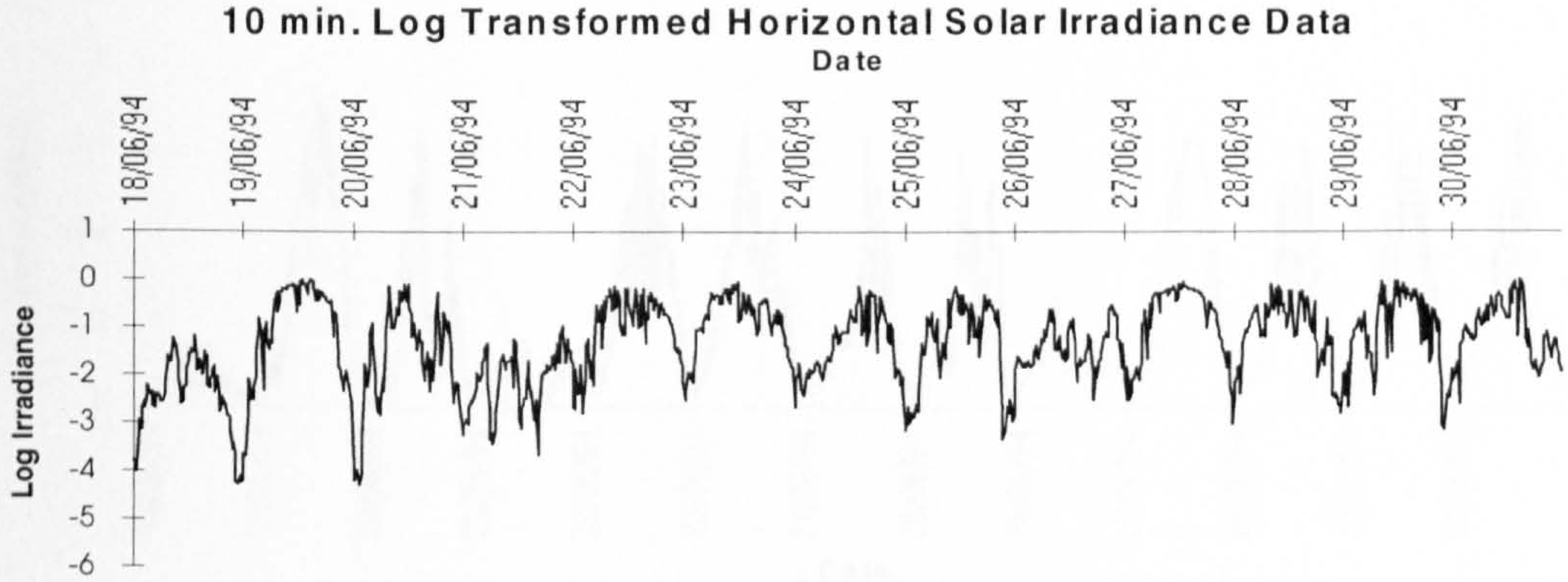
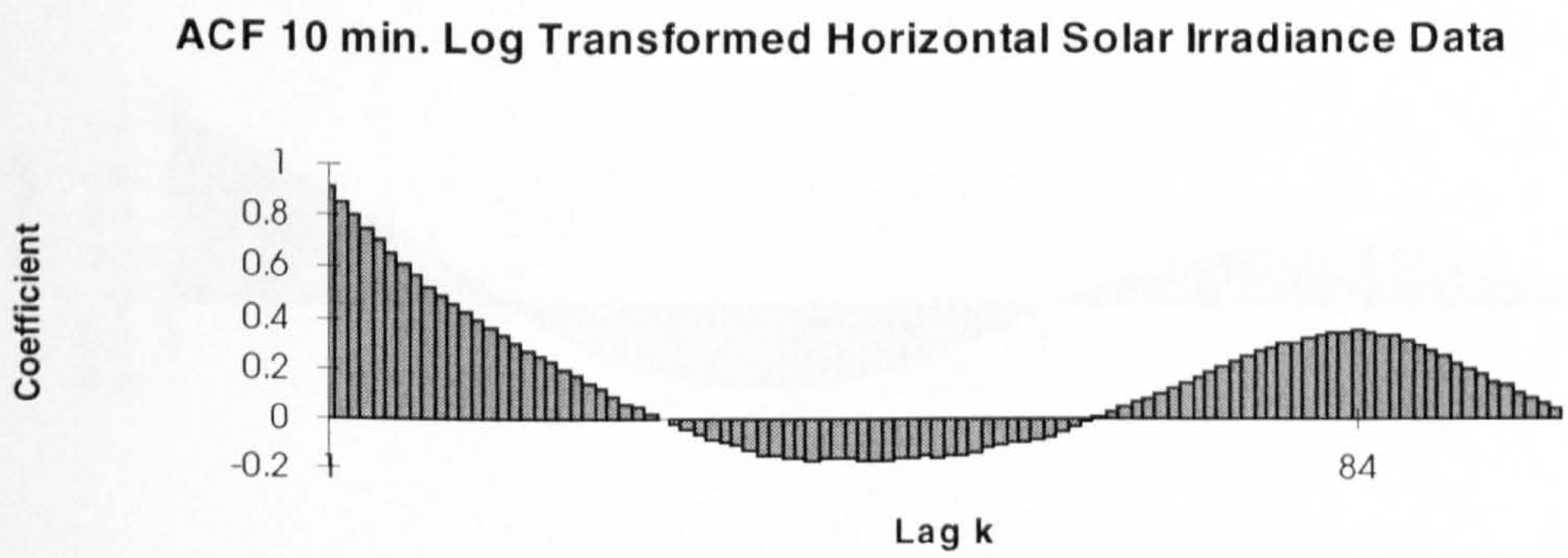


Figure 4.9.2 Log transformed Horizontal Solar Irradiance - 10 minute averages, JUN94_10

a)



b)



c)

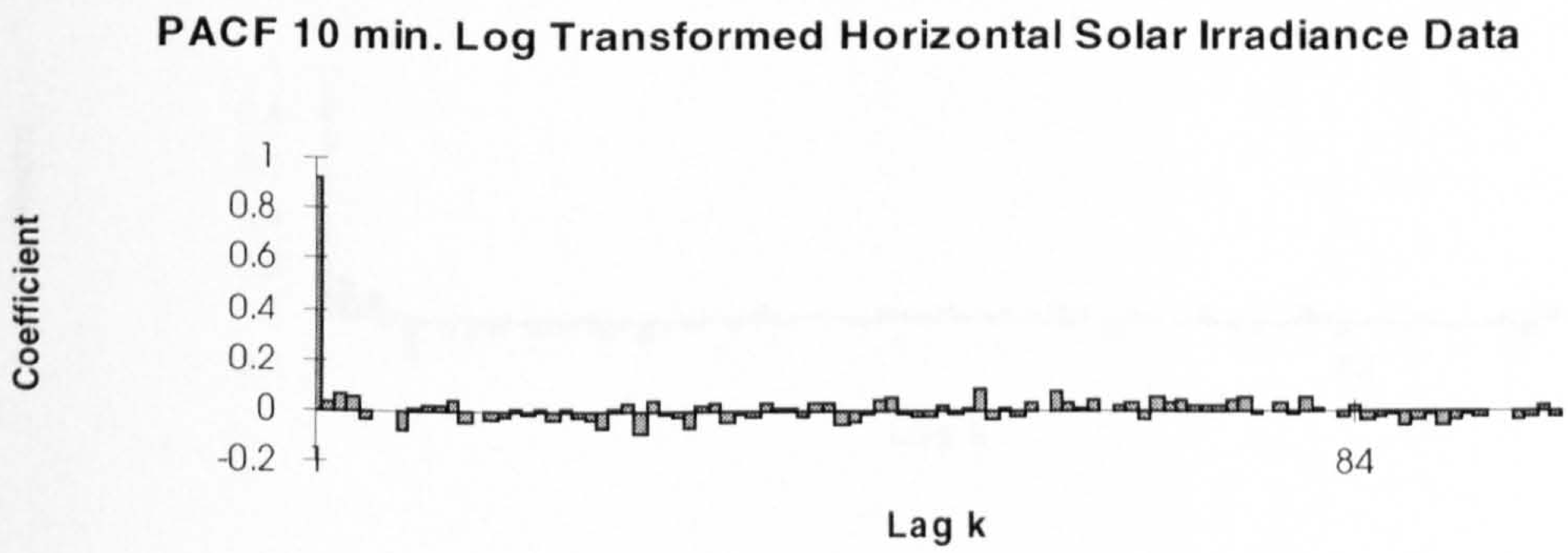
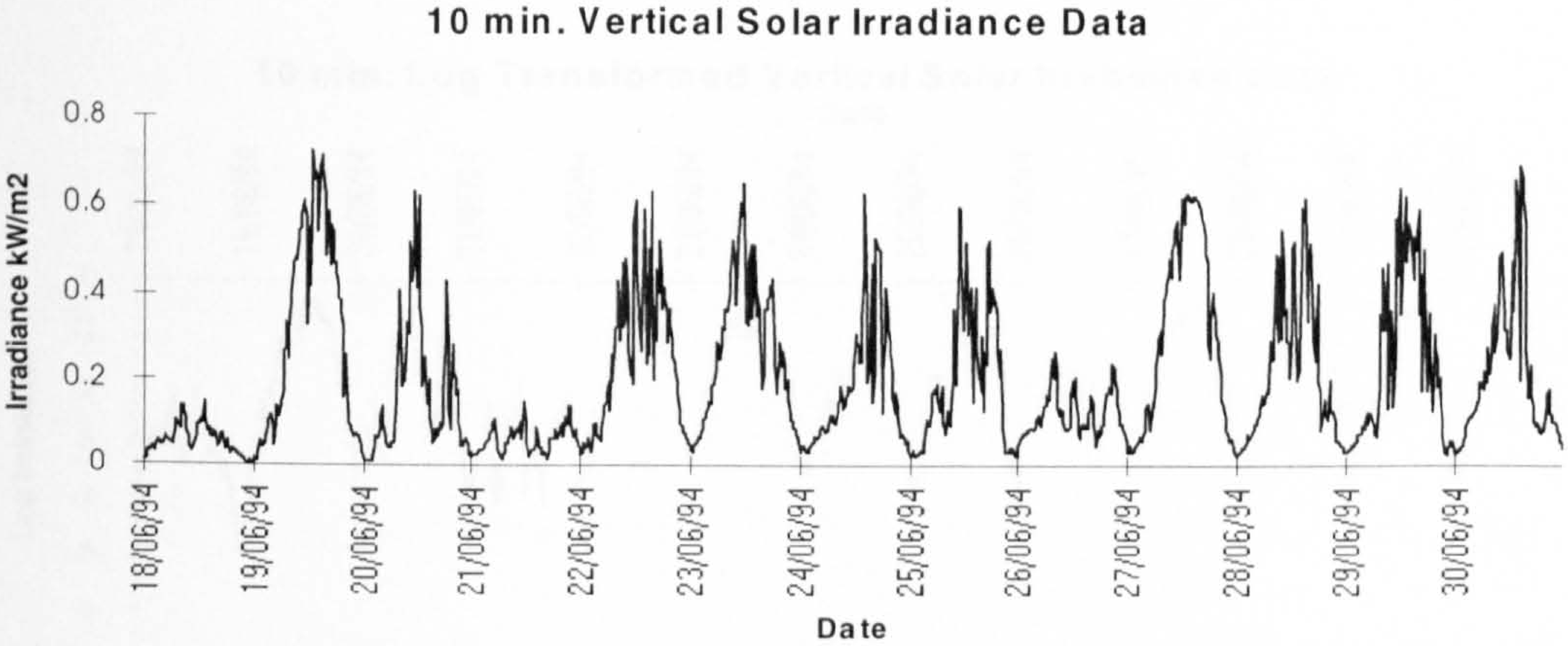
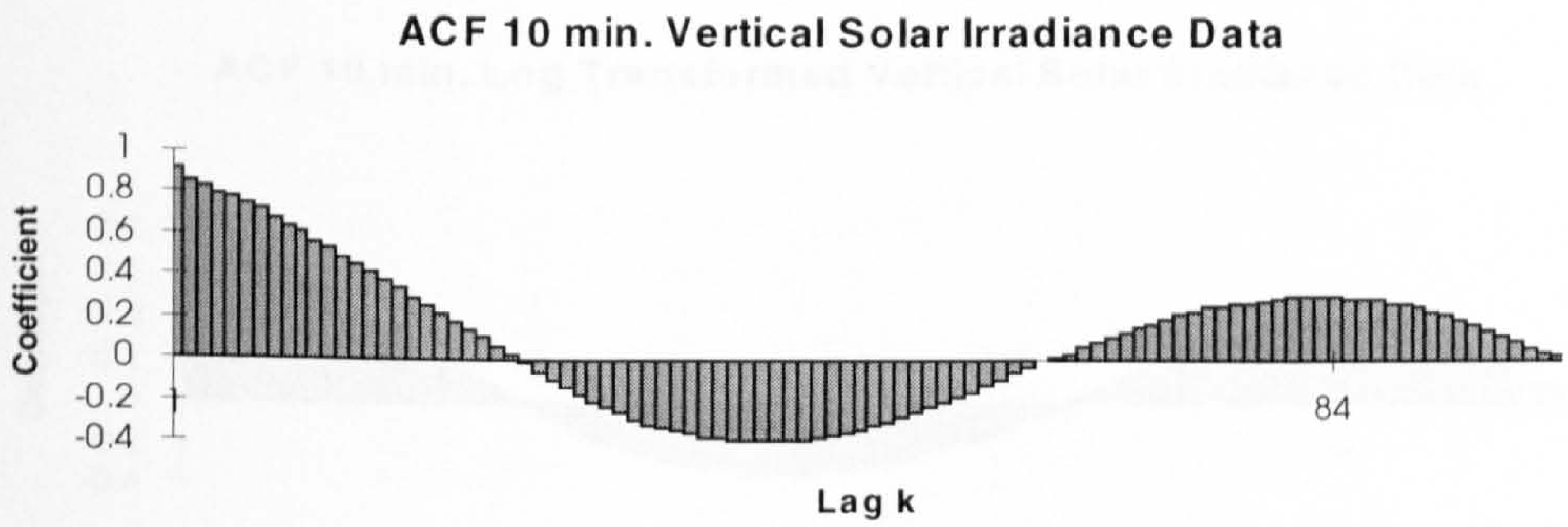


Figure 4.9.3 Vertical Solar Irradiance - 10 minute averages, JUN94_10

a)



b)



c)

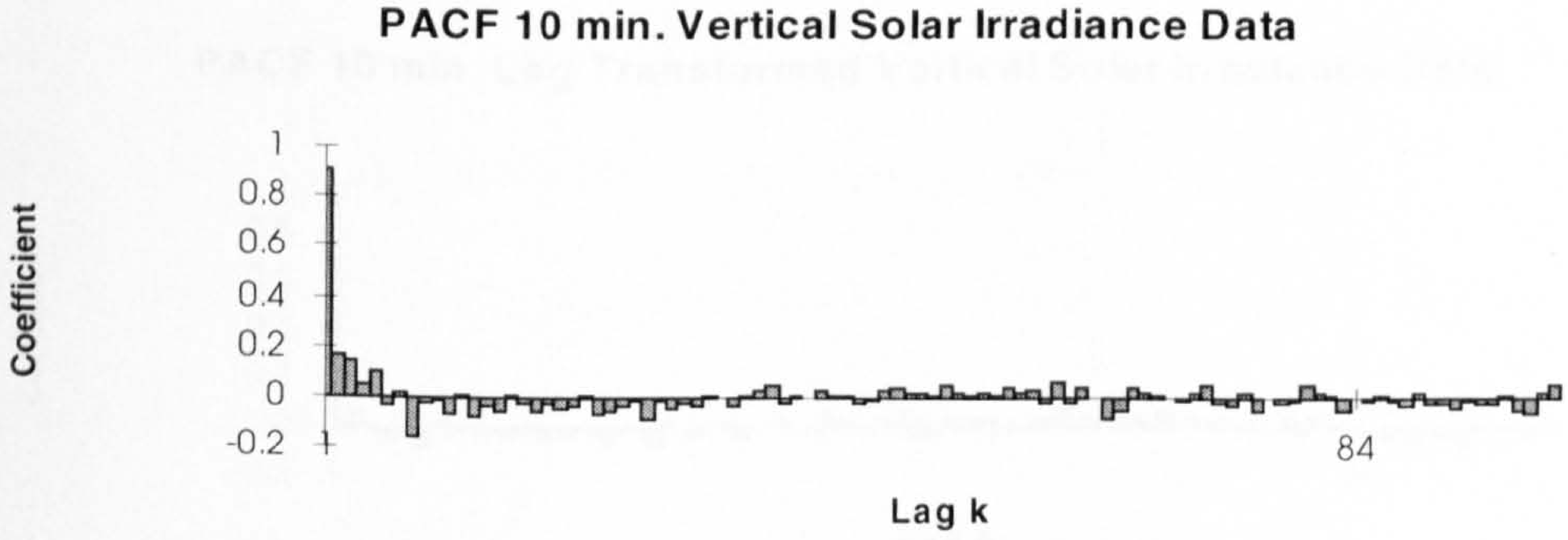
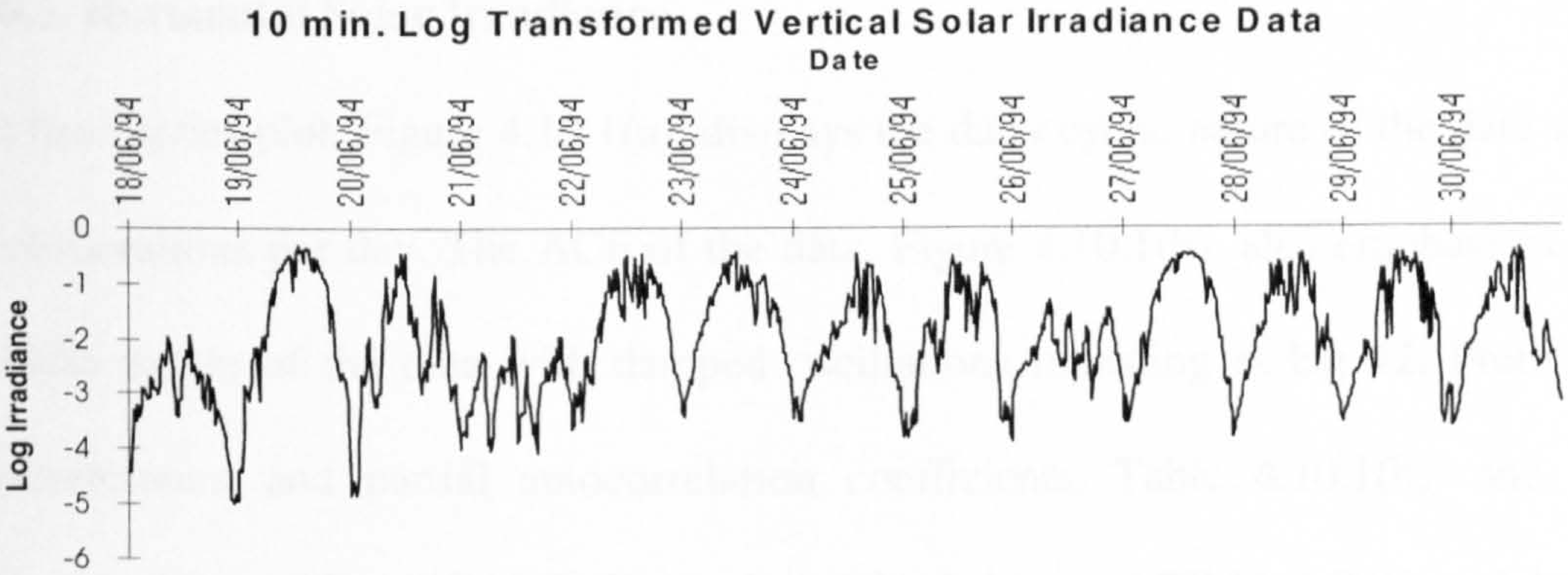
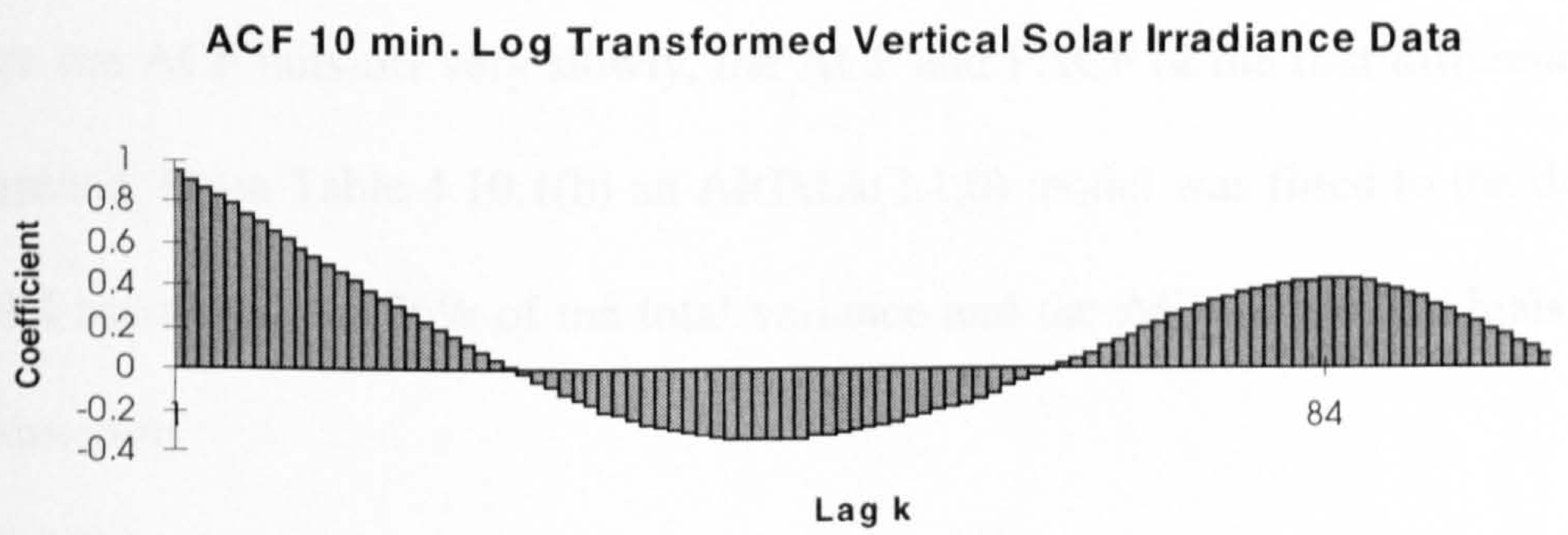


Figure 4.9.4 Log transformed Vertical Solar Irradiance - 10 minute averages, JUN94_10

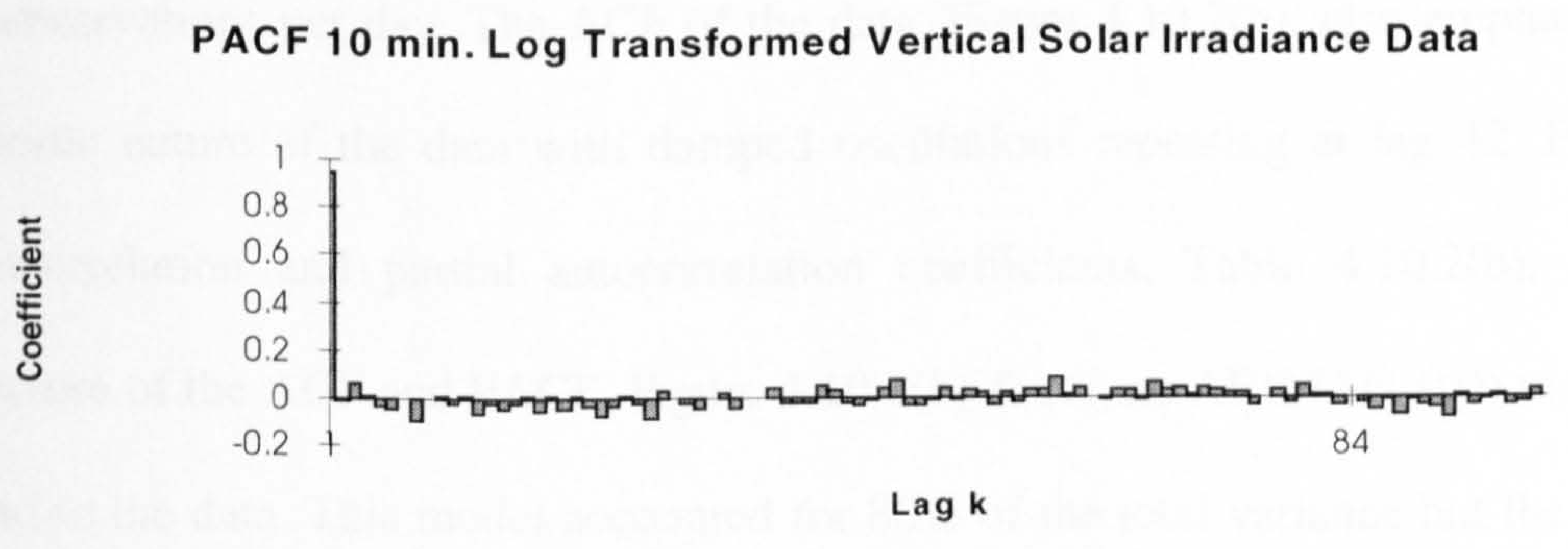
a)



b)



c)



4.10. June 1994 (18th - 30th) - Twenty minute averages

This data set, known as JUN94_20(18th-30th), contains 20 minute averaged Solar Irradiance data recorded between 18th and 30th June 1994.

4.10.1. Horizontal Solar Irradiance

The time series plot, Figure 4.10.1(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.10.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.10.1(b), and the structure of the ACF and PACF, Figure 4.10.1(b) & (c), an ARIMA(2,0,0) model was fitted to the to the data. This model accounted for 77% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.10.1(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 76% of the total variance and the ACF of the residuals showed no structure.

4.10.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.10.2(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.10.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.10.2(b), and the structure of the ACF and PACF, Figure 4.10.2(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 80% of the total variance but the ACF of the residuals had a significant value at lag 42. An ARIMA(1,0,0)(1,0,0)42 model was then fitted to the data, but the backforecasts did notdie out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.10.2(b) the ACF and the PACF of the differenced series showed no structure and an ARIMA model could not be determined.

4.10.3. Vertical Solar Irradiance

The time series plot, Figure 4.10.3(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.10.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.10.3(b), and the structure of the ACF and PACF, Figure 4.10.3(b) & (c), an ARIMA(2,0,0) model was fitted to the data. This model accounted for 82% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.10.3(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 81% of the total variance but the ACF of the residuals had a significant value at lag41. Fitting an ARIMA(2,1,0)(1,0,0)42 did not significantly improve the model.

4.10.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.10.4(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.10.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.10.4(b), and the structure of the ACF and PACF, Figure 4.10.4(b) & (c), an ARIMA(1,0,0) model was fitted to the data. However, the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.10.4(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 86% of the total variance and the ACF of the residuals showed no structure.

Table 4.10.1 Summary information for Horizontal Solar Irradiance - 20 minute averages (datafile JUN94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.3609	0.2459	0.0143	0.9762

b)

$2/\sqrt{546} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.873	0.873	-0.181	-0.181
2	0.792	0.124	-0.071	-0.107
3	0.729	0.063	0.029	-0.004
4	0.659	-0.036	0.030	0.029
42	0.264	-0.041	0.011	0.003

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)	AR1	0.7667	0.0426	18.01	7.55653	0.01392	77
	AR2	0.1269	0.0425	2.98			
	CONST	0.0375	0.0051	7.41			
ARIMA(2,1,0)	AR1	-0.2004	0.0427	-4.70	7.83331	0.01443	76
	AR2	-0.1072	0.0427	-2.51			
ARIMA(2,0,0)(1,0,0)42	AR1	0.7587	0.0427	17.76	7.53914	0.01391	77
	AR2	0.1326	0.0426	3.11			
	SAR42	0.0501	0.0450	1.11			
	CONST	0.0363	0.00505	7.19			
ARIMA(2,1,0)(1,0,0)42	AR1	-0.2105	0.0429	-4.91	7.81045	0.01441	76
	AR2	-0.1152	0.0428	-2.69			
	SAR42	0.0579	0.0451	1.28			

Table 4.10.2 Summary information for Log Transformed Horizontal Solar Irradiance - 20 minute averages (datafile JUN94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.3205	0.8650	-4.2510	-0.0241

b)

$2/\sqrt{546} = 0.086$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.889	0.889	-0.020	-0.020
2	0.784	-0.025	-0.005	-0.005
3	0.684	-0.038	-0.031	-0.032
4	0.593	-0.016	-0.026	-0.027
42	0.361	-0.041	0.083	0.036

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.9039	0.0188	48.10	79.3384	0.1458	80
	CONST	-0.1318	0.0164	-8.05			
ARIMA(1,0,0)(1,0,0)42	AR1	0.8941	0.0191	46.81	79.6461	0.14668	80
	SAR42	0.1084	0.0437	2.98			
	CONST	-1.3733	0.1692	-8.12			
ARIMA(2,1,0)	AR1	-0.0200	0.0429	-0.47	83.9795	0.2547	79
	AR2	-0.0051	0.0430	-0.12			

Table 4.10.3 Summary information for Vertical Solar Irradiance - 20 minute averages (datafile JUN94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2002	0.1716	0.0071	0.6964

b)

$2/\sqrt{546} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.903	0.903	-0.160	-0.160
2	0.838	0.116	-0.063	-0.091
3	0.784	0.057	0.101	0.078
4	0.711	-0.111	0.040	0.067
42	0.315	-0.053	0.003	-0.023

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)	AR1	0.7997	0.0426	18.77	2.8567	0.00526	82
	AR2	0.1186	0.0426	2.78			
	CONST	0.0157	0.0031	5.07			
ARIMA(3,0,0)	AR1	0.7929	0.0429	18.49	2.84726	0.00525	82
	AR2	0.0726	0.0546	1.33			
	AR3	0.0577	0.0429	1.35			
	CONST	0.0147	0.0031	4.74			
ARIMA(2,1,0)	AR1	-0.1748	0.0427	-4.09	2.93856	0.00541	81
	AR2	-0.0914	0.0427	-2.14			
ARIMA(2,1,0)(1,0,0)42	AR1	-0.1860	0.0431	-4.31	2.93142	0.00541	81
	AR2	-0.0999	0.0429	-2.33			
	SAR42	0.0539	0.0459	1.18			

Table 4.10.4 Summary information for Log Transformed Vertical Solar Irradiance - 20 minute averages (datafile JUN94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0294	0.9846	-4.9477	-0.3618

b)

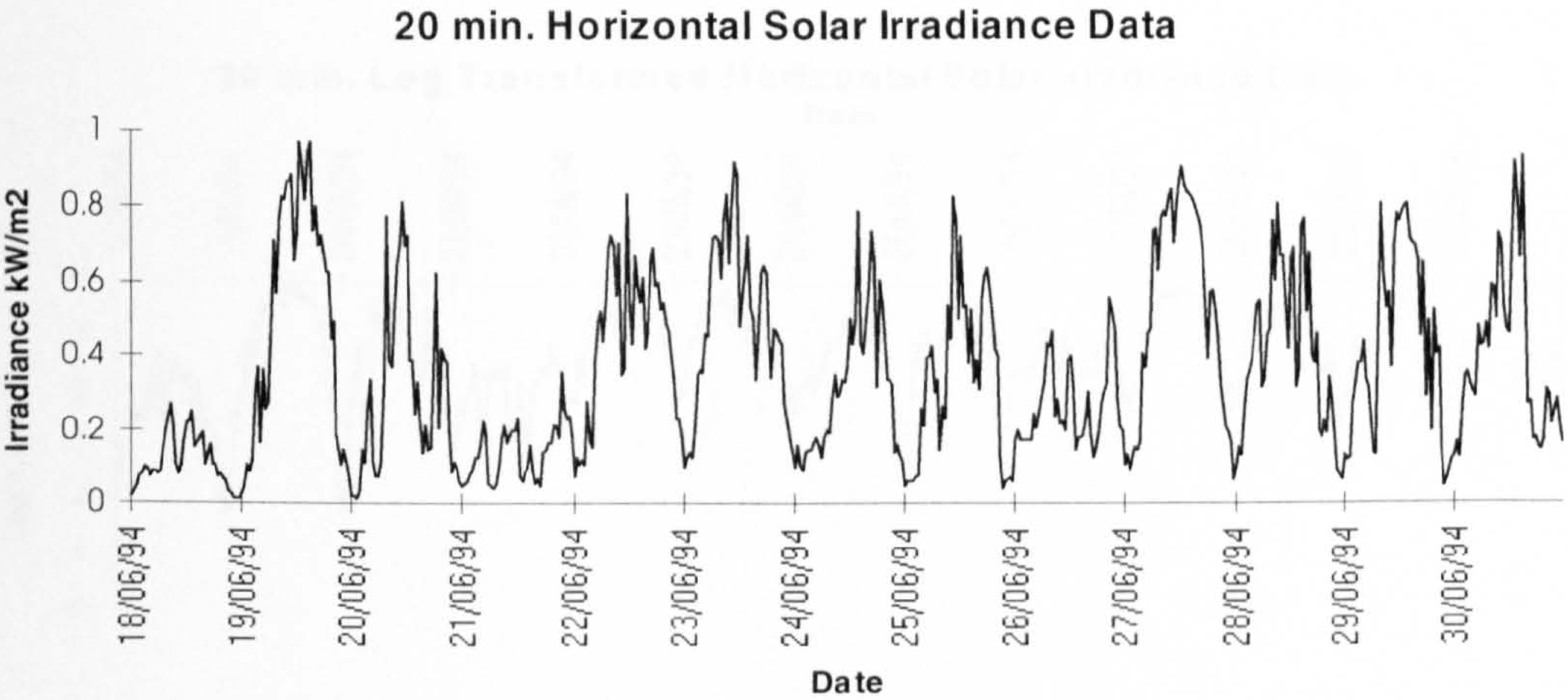
$2/\sqrt{546} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.926	0.926	0.062	0.062
2	0.848	-0.073	0.049	0.046
3	0.765	-0.072	0.021	0.015
4	0.680	-0.057	0.014	0.010
42	0.435	-0.047	0.105	0.056

c)

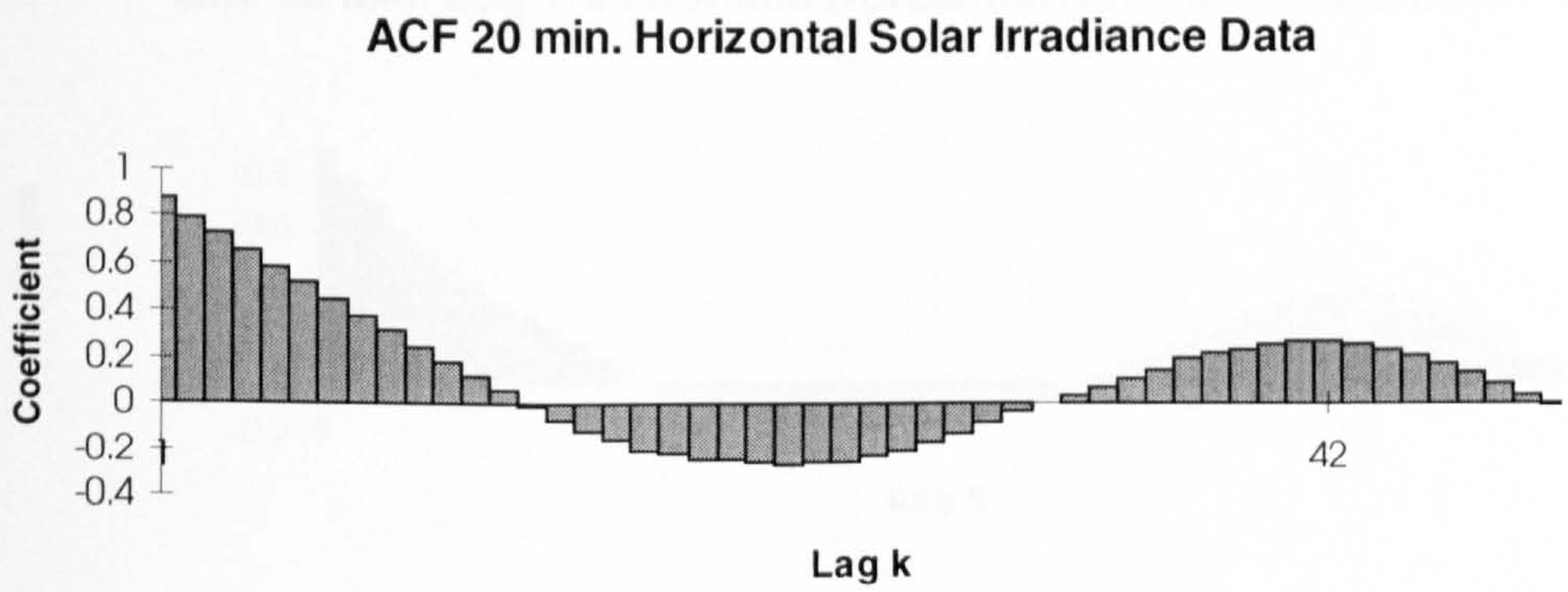
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.9384	0.0154	60.97	68.5937	0.1261	87
	CONST	-0.130	0.0153	-8.55			
ARIMA(1,0,0)(1,0,0)42	AR1	0.9289	0.0157	59.10	68.337	0.1252	87
	AR2	0.1287	0.0437	2.94			
	SAR42	-2.1159	0.2364	-8.95			
ARIMA(2,1,0)	AR1	0.0600	0.0429	1.40	70.7176	0.1302	86
	AR2	0.0464	0.0429	1.08			
ARIMA(0,1,0)(1,0,0)42	SAR42	0.109	0.0438	2.50	70.3296	0.12916	86

Figure 4.10.1 Horizontal Solar Irradiance - 20 minute averages, JUN94_20

a)



b)



c)

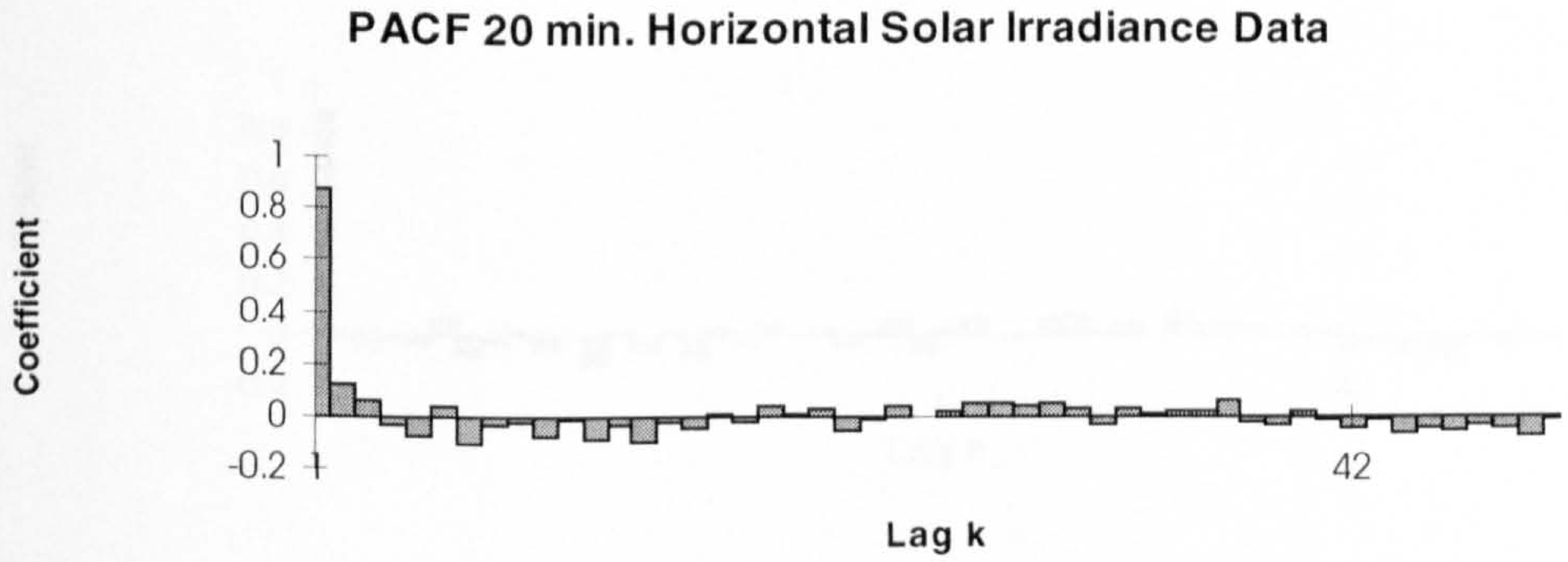
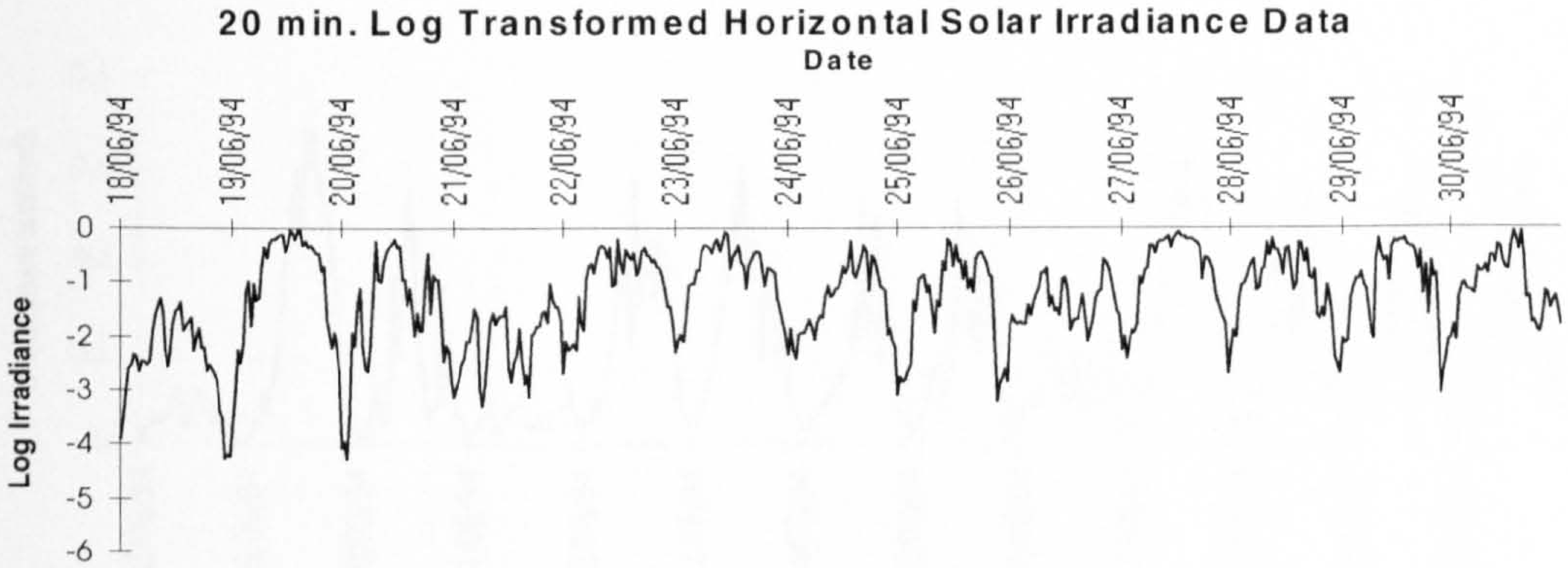
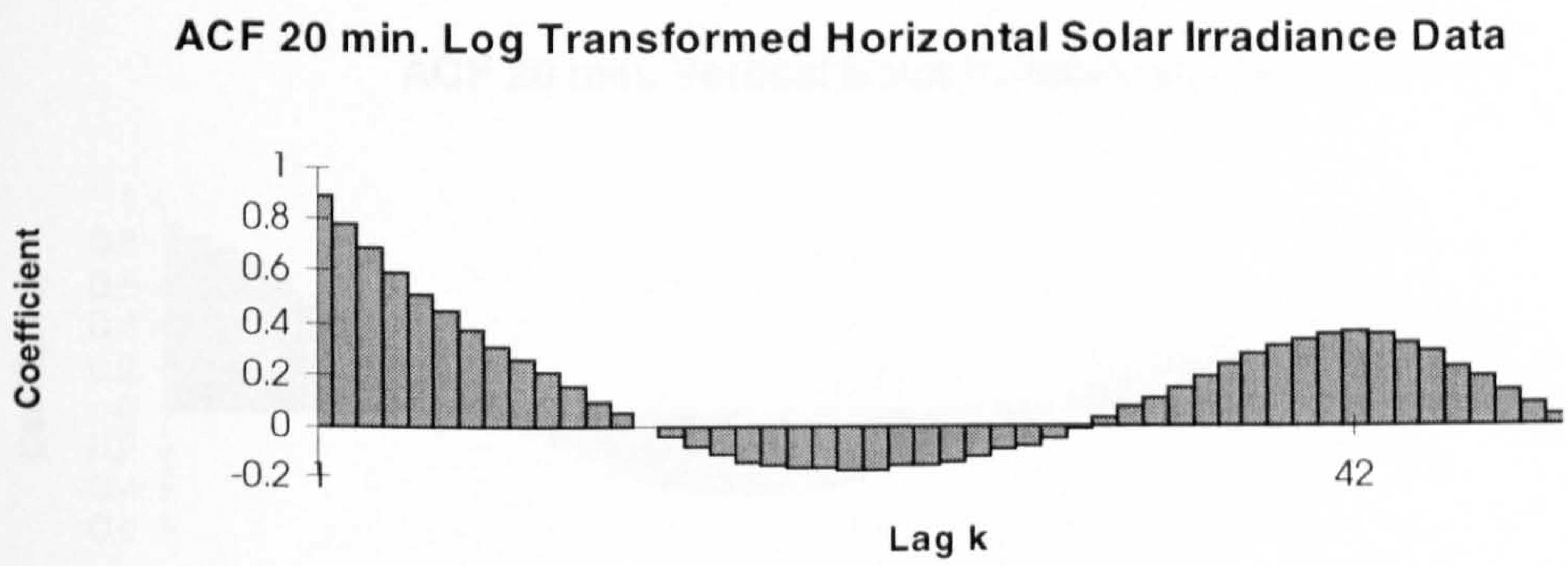


Figure 4.10.2 Log transformed Horizontal Solar Irradiance - 20 minute averages, JUN94_20

a)



b)



c)

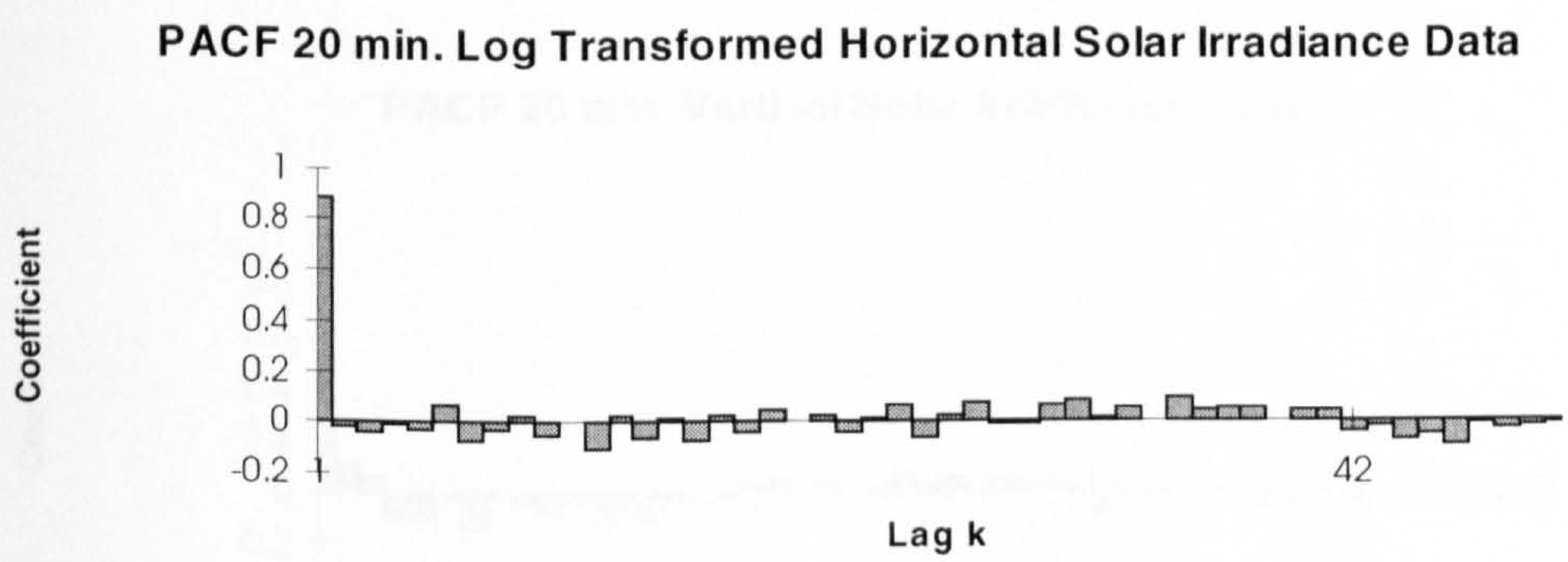
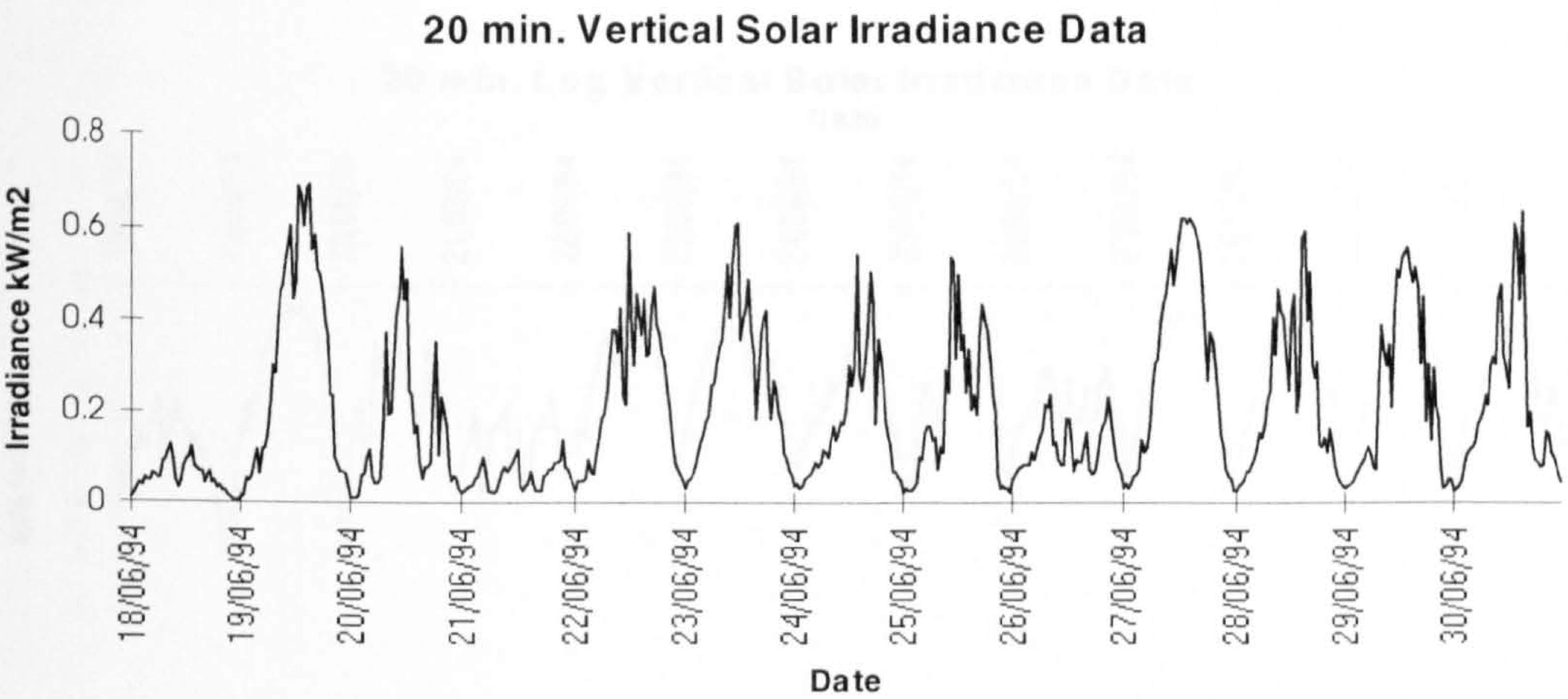
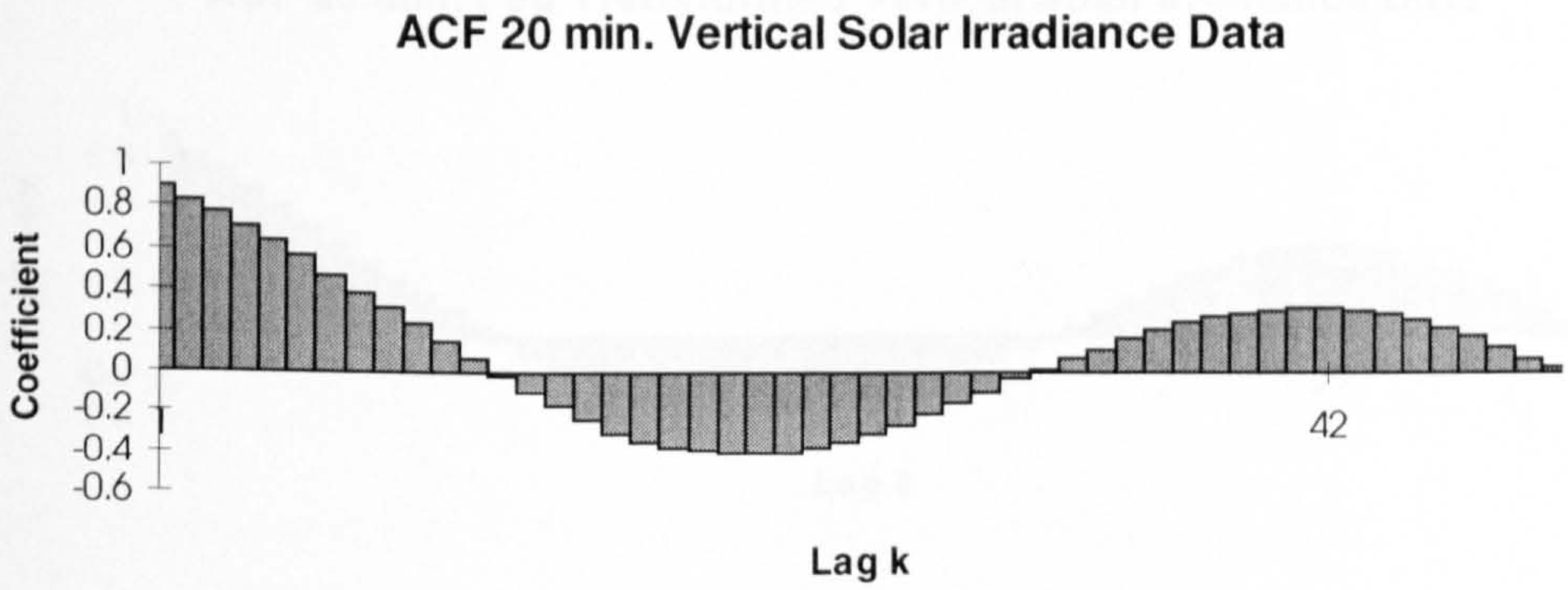


Figure 4.10.3 Vertical Solar Irradiance - 20 minute averages, JUN94_20

a)



b)



c)

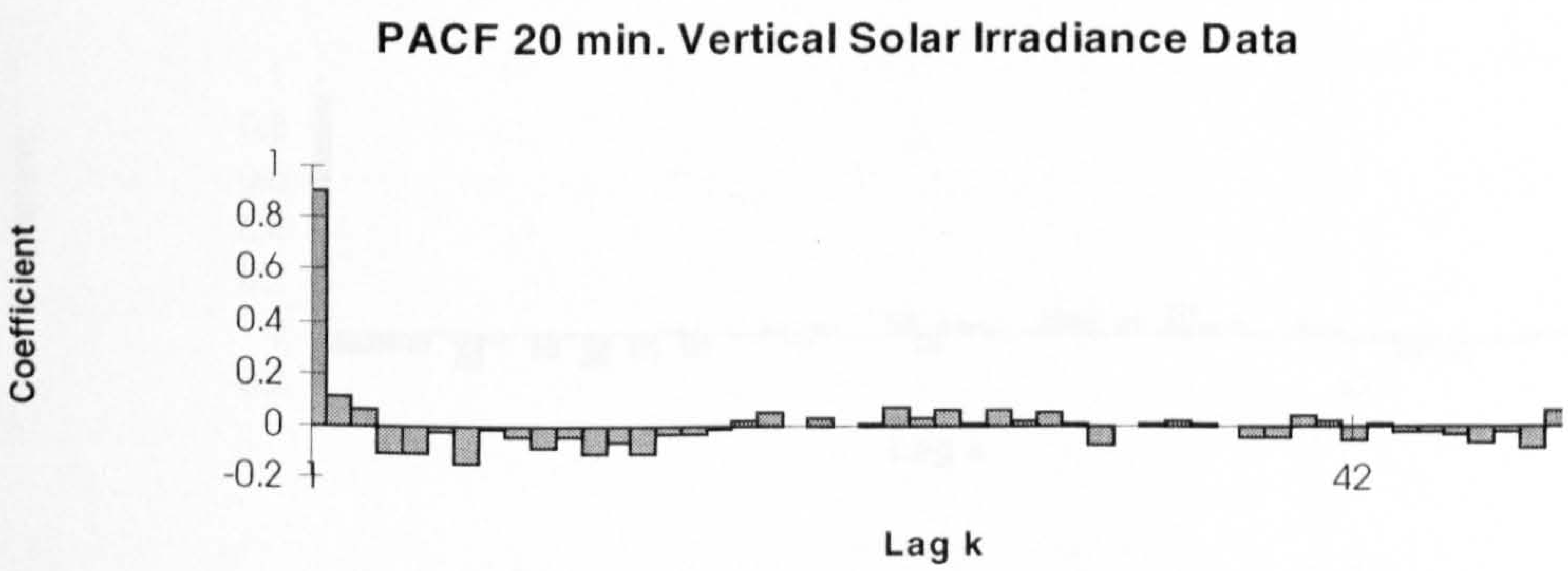
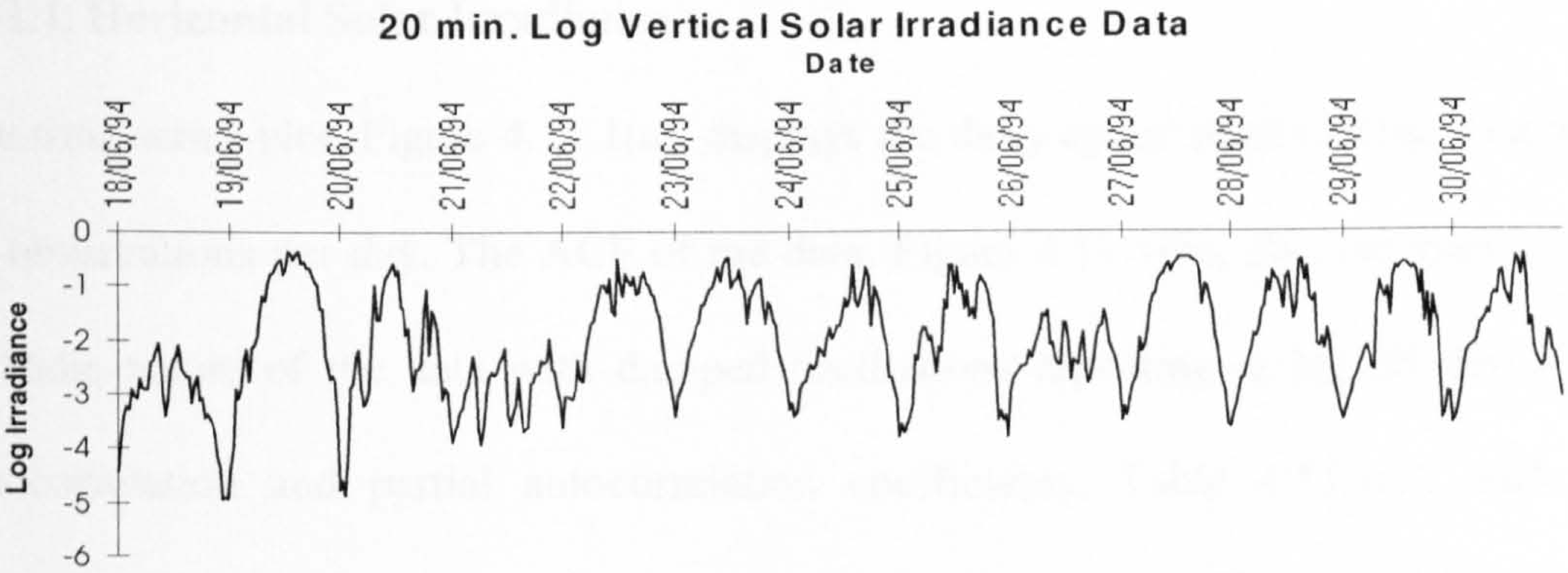
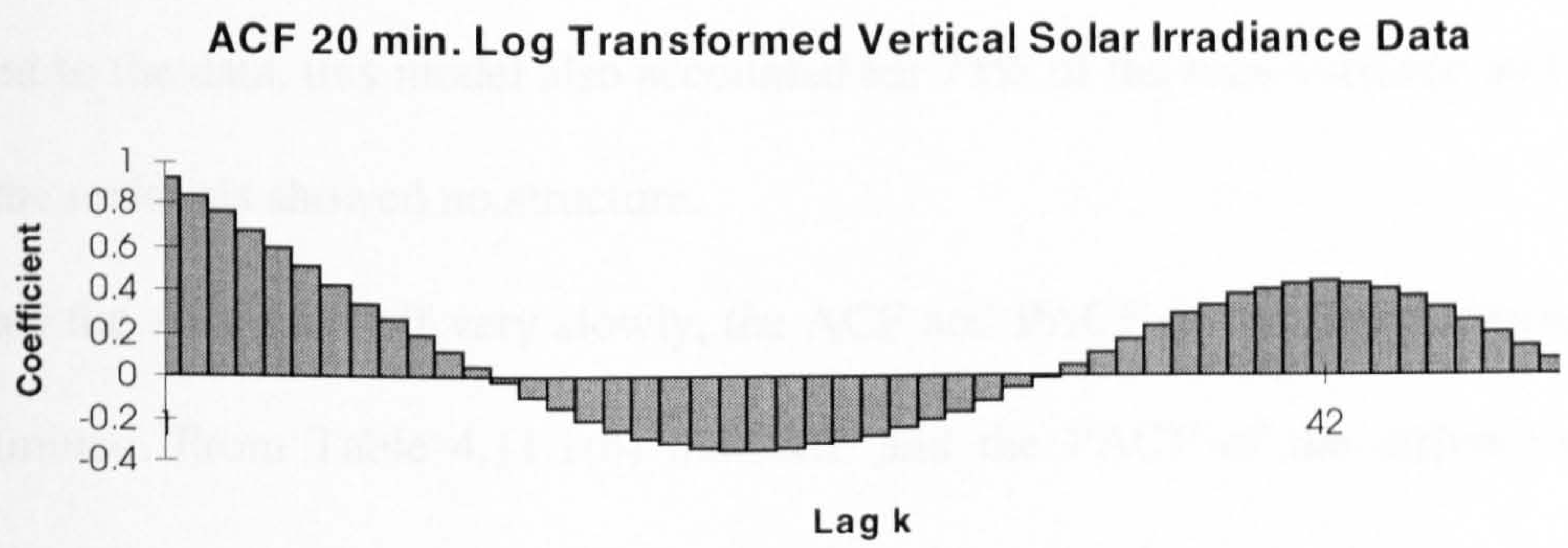


Figure 4.10.4 Log transformed Vertical Solar Irradiance - 20 minute averages, JUN94_20

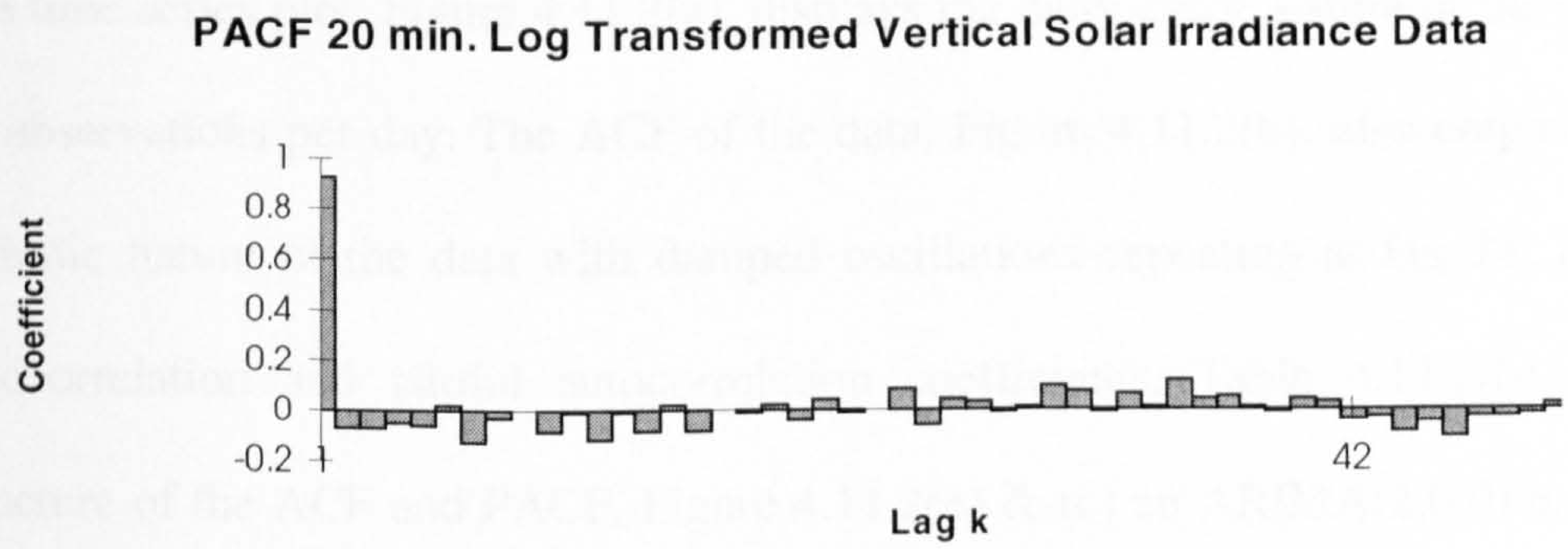
a)



b)



c)



4.11. June 1994 (18th - 30th) - Thirty minute averages

This data set, known as JUN94_30(18th-30th), contains 30 minute averaged Solar Irradiance data recorded between 18th and 30th June 1994.

4.11.1. Horizontal Solar Irradiance

The time series plot, Figure 4.11.1(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.11.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.11.1(b), and the structure of the ACF and PACF, Figure 4.11.1(b) & (c), an ARIMA(1,0,0) model to the data. This model accounted for 75% of the total variance but the ACF of the residuals had a significant value at lag 28. An ARIMA(1,0,0)(1,0,0)28 model was fitted to the data, this model also accounted for 75% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.11.1(b) the ACF and the PACF of the differenced series showed no structure and an ARIMA model could not be determined.

4.11.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.11.2(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.11.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.11.2(b), and the structure of the ACF and PACF, Figure 4.11.2(b) & (c) an ARIMA(2,0,0) model was fitted to the data. This model accounted for 77% of the total variance but the ACF of the residuals had a significant value at lag 28. An ARIMA(2,0,0)(1,0,0)28 model was fitted to the data, this model also accounted for 77% of the total variance but the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.11.2(b) an ARIMA(2,1,0) model was fitted to the data. This model also accounted for 75% of the total variance but the ACF of the residuals had a significant value at lag 28. An ARIMA(2,1,0)(1,0,0)28 model was fitted to the data, this model accounted for 76% of the total variance and the ACF of the residuals showed no structure.

4.11.3. Vertical Solar Irradiance

The time series plot, Figure 4.11.3(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.11.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.11.3(b), and the structure of the ACF and PACF, Figure 4.11.3(b) & (c), an ARIMA(1,0,0) model to the data. This model accounted for 80% of the total variance but the ACF of the residuals was not consistent with a 'white noise' process. An ARIMA(1,0,0)(1,0,0)28 model was fitted to the data, this model also accounted for 80% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.11.3(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model could not be determined.

4.11.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.11.4(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.11.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.11.4(b), and the structure of the ACF and PACF, Figure 4.11.4(b) & (c), an ARIMA(1,0,0) model was fitted to the data, this model accounted for 83% of the total variance but the ACF of the residuals had a significant value at lag1.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.11.4(b) an ARIMA(1,1,0) model. This model also accounted for 83% of the total variance but the ACF of the residuals had a significant value at lag 28. An ARIMA(1,1,0)(1,0,0)28 model was fitted to the data, this model accounted for 84% of the total variance and the ACF of the residuals showed no structure.

Table 4.11.1 Summary information for Horizontal Solar Irradiance - 30 minute averages (datafile JUN94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.3609	0.2421	0.0143	0.9750

b)

$2/\sqrt{364} = 0.105$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.861	0.861	-0.084	-0.084
2	0.746	0.018	-0.049	-0.057
3	0.644	-0.007	0.033	0.025
4	0.534	-0.086	-0.020	-0.018
28	0.275	-0.054	0.100	0.045

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8670	0.0264	32.86	5.37684	0.01485	75
	CONST	0.0468	0.0064	7.32			
ARIMA(1,0,0)(1,0,0)28	AR1	0.8596	0.0272	31.61	5.2918	0.01466	75
	SAR28	0.1327	0.0551	2.41			
	CONST	0.0427	0.00635	6.72			
ARIMA(1,1,0)(1,0,0)28	AR1	-0.1059	0.0527	-2.01	5.64936	0.01563	73
	SAR28	0.1233	0.0555	2.22			

Table 4.11.2 Summary information for Log Transformed Horizontal Solar Irradiance - 30 minute averages (datafile JUN94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.3110	0.8519	-4.2475	-0.0253

b)

$2/\sqrt{364} = 0.105$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.861	0.861	0.120	0.120
2	0.700	-0.158	-0.093	-0.109
3	0.566	0.019	-0.071	-0.047
4	0.543	-0.019	-0.055	-0.052
28	0.370	-0.006	0.188	0.101

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)	AR1	1.0543	0.0516	20.44	59.5505	0.1650	77
	AR2	-0.1970	0.0512	-3.55			
	CONST	-0.1930	0.0213	-9.06			
ARIMA(2,0,0)(1,0,0)28	AR1	1.0065	0.0522	19.27	58.9794	0.1627	77
	AR2	-0.1615	0.0519	-3.11			
	SAR28	0.1916	0.0529	3.62			
	CONST	-1.3633	0.1638	-8.32			
ARIMA(2,1,0)	AR1	0.1349	0.0524	2.57	64.8272	0.1796	75
	AR2	-0.1101	0.0524	-2.10			
ARIMA(2,1,0)(1,0,0)28	AR1	0.0878	0.0525	1.67	62.0478	0.1724	76
	AR2	-0.1469	0.0523	-2.81			
	SAR28	0.2210	0.0529	4.18			

Table 4.11.3 Summary information for Vertical Solar Irradiance - 30 minute averages (datafile JUN94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2002	0.1696	0.0071	0.6919

b)

$2/\sqrt{364} = 0.105$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.893	0.893	-0.053	-0.053
2	0.797	0.001	0.044	0.041
3	0.692	-0.094	0.105	0.110
4	0.567	-0.171	-0.017	-0.008
28	0.325	-0.063	0.092	-0.003

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8975	0.0234	38.34	2.07254	0.00573	80
	CONST	0.0193	0.0039	4.97			
ARIMA(1,0,0)(1,0,0)28	AR1	0.8906	0.0243	36.68	2.04446	0.00566	80
	SAR28	0.1243	0.0558	2.23			
	CONST	0.01838	0.00395	4.66			

Table 4.11.4 Summary information for Log Transformed Vertical Solar Irradiance - 30 minute averages (datafile JUN94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0218	0.9771	-4.9430	-0.3683

b)

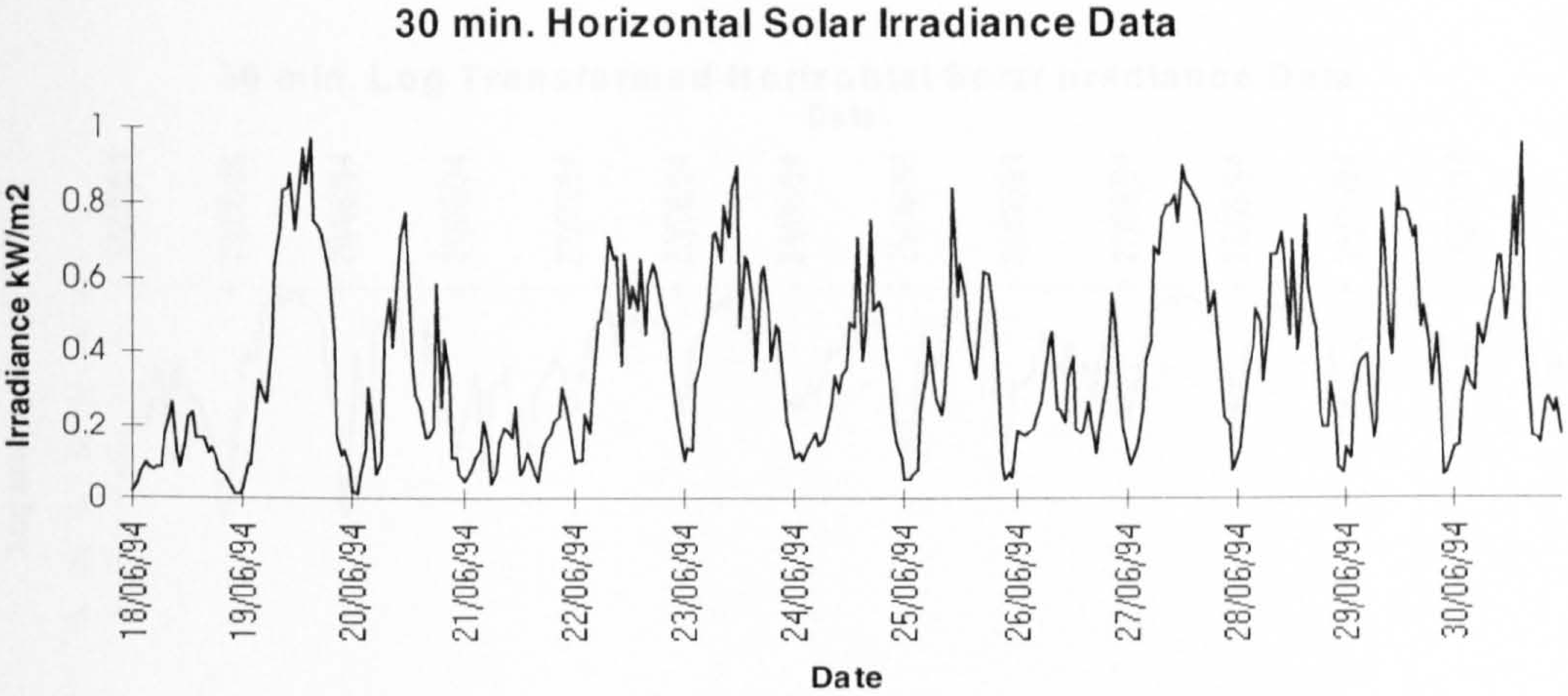
$2/\sqrt{364} = 0.105$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.903	0.903	0.215	0.215
2	0.776	-0.217	0.007	-0.041
3	0.648	-0.046	0.011	0.019
4	0.522	-0.077	-0.014	-0.021
28	0.443	-0.023	0.236	0.115

c)

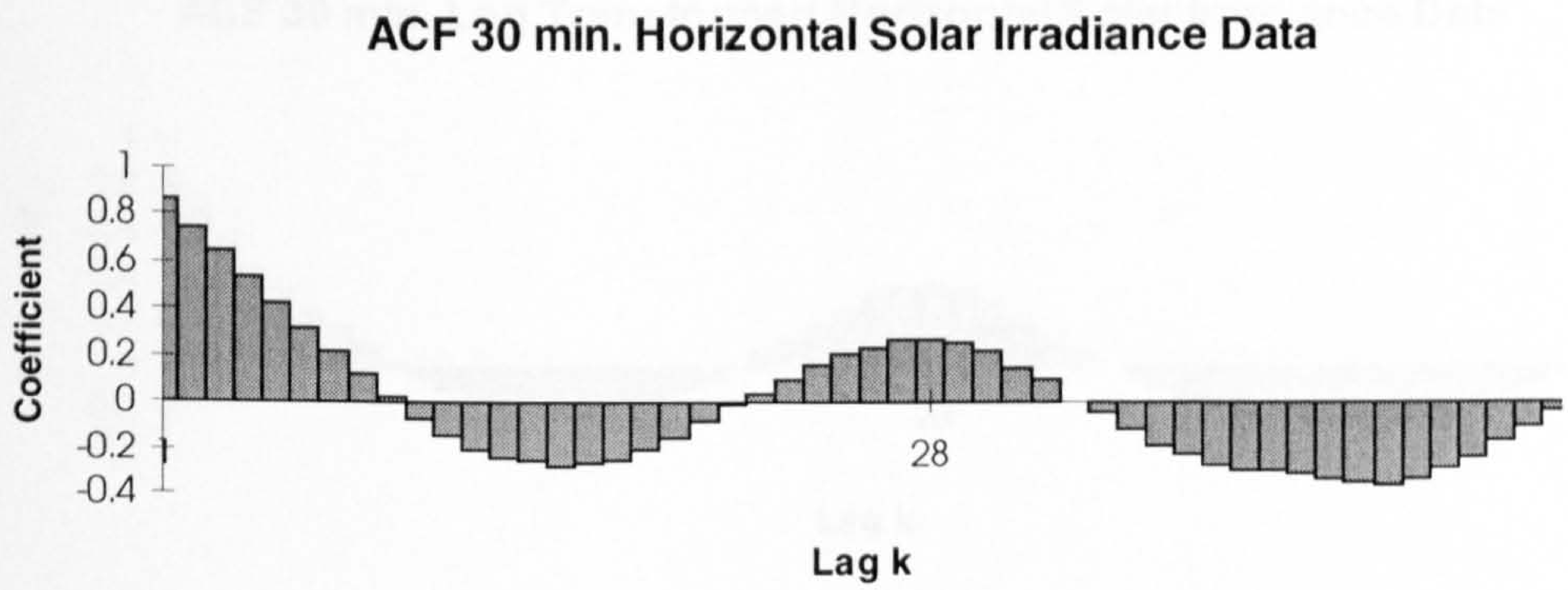
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.9198	0.0214	42.97	58.0723	0.1604	83
	CONST	-0.1699	0.0211	-8.06			
ARIMA(1,1,0)	AR1	0.2191	0.0514	4.27	58.0125	0.1603	83
ARIMA(1,1,0)(1,0,0)28	AR1	0.1571	0.0523	3.00	55.5997	0.1540	84
	SAR28	0.2196	0.0530	4.14			

Figure 4.11.1 Horizontal Solar Irradiance - 30 minute averages, JUN94_30

a)



b)



c)

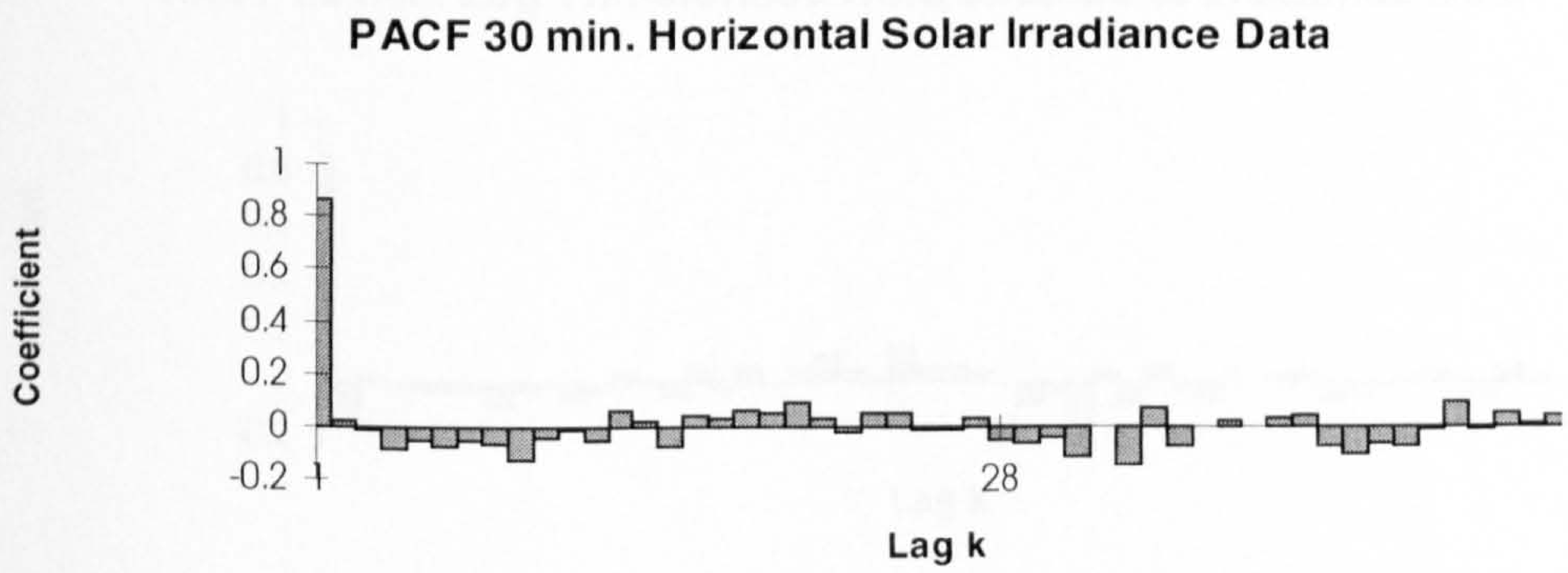
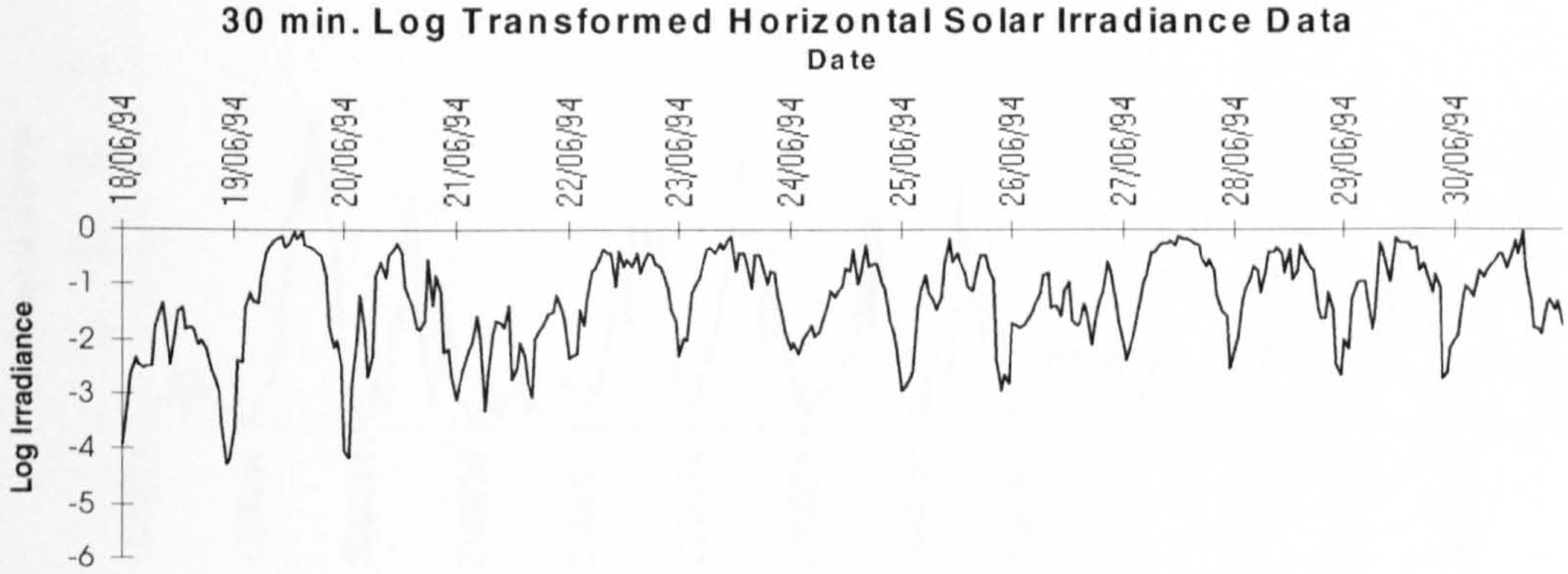
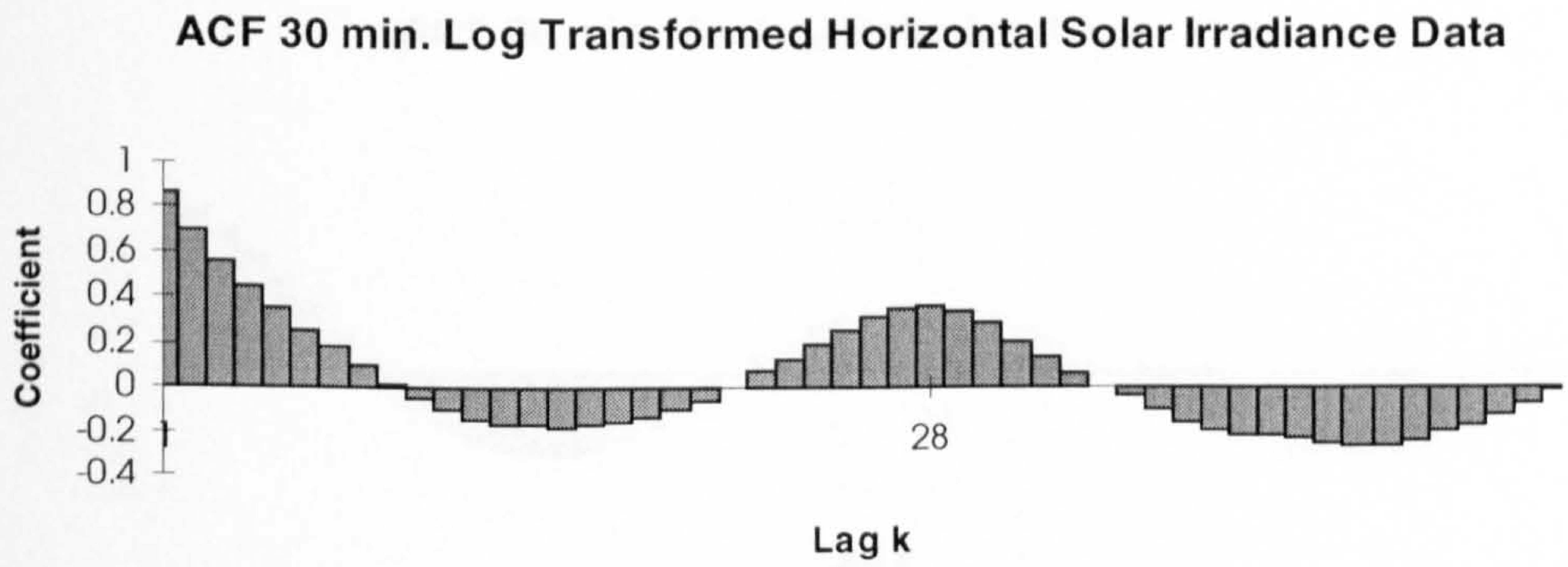


Figure 4.11.2 Log transformed Horizontal Solar Irradiance - 30 minute averages, JUN94_30

a)



b)



c)

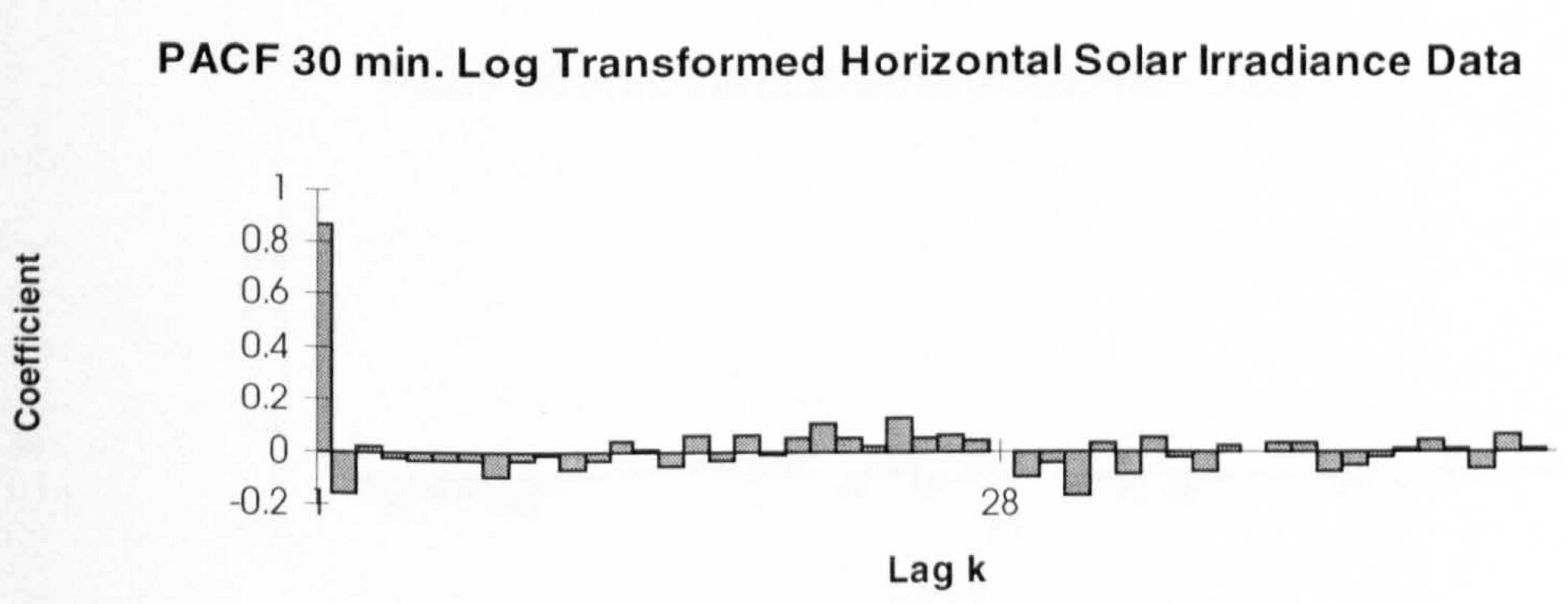
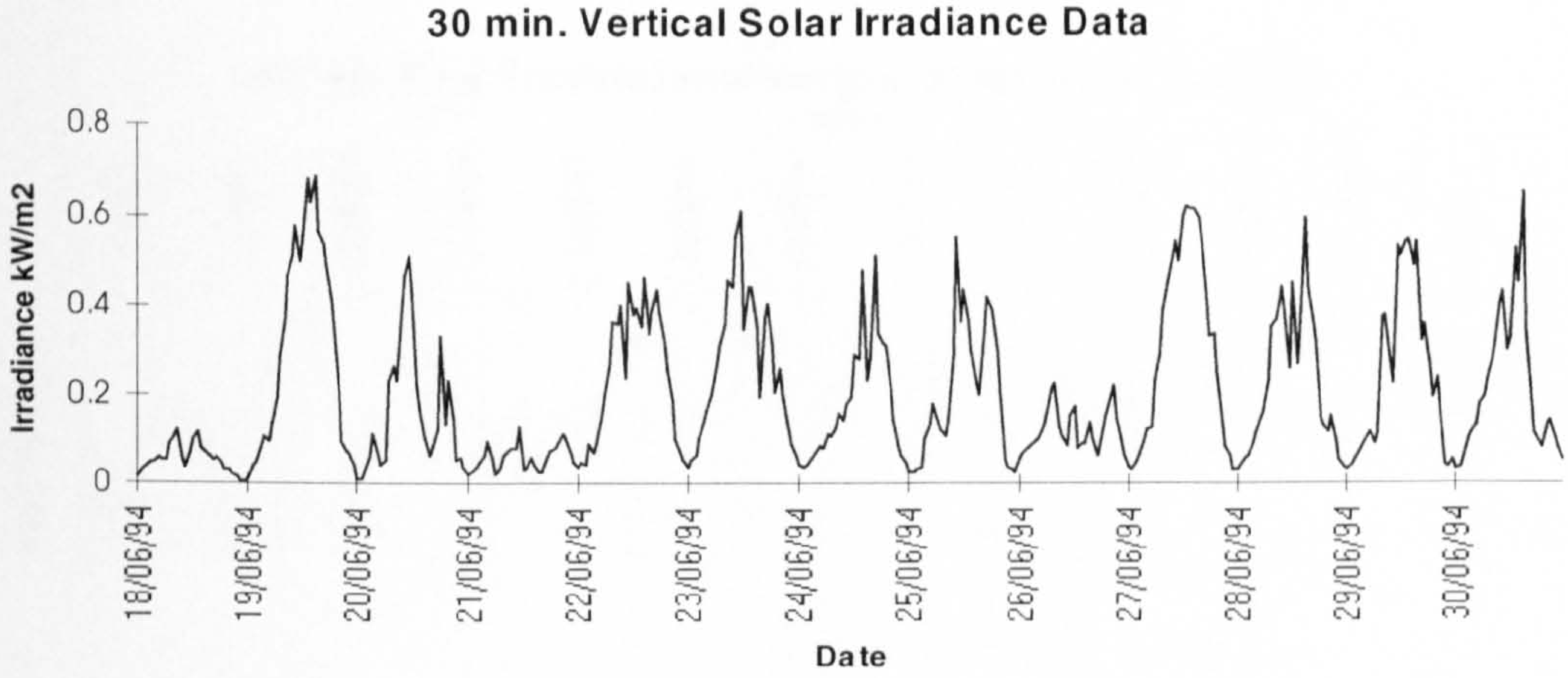
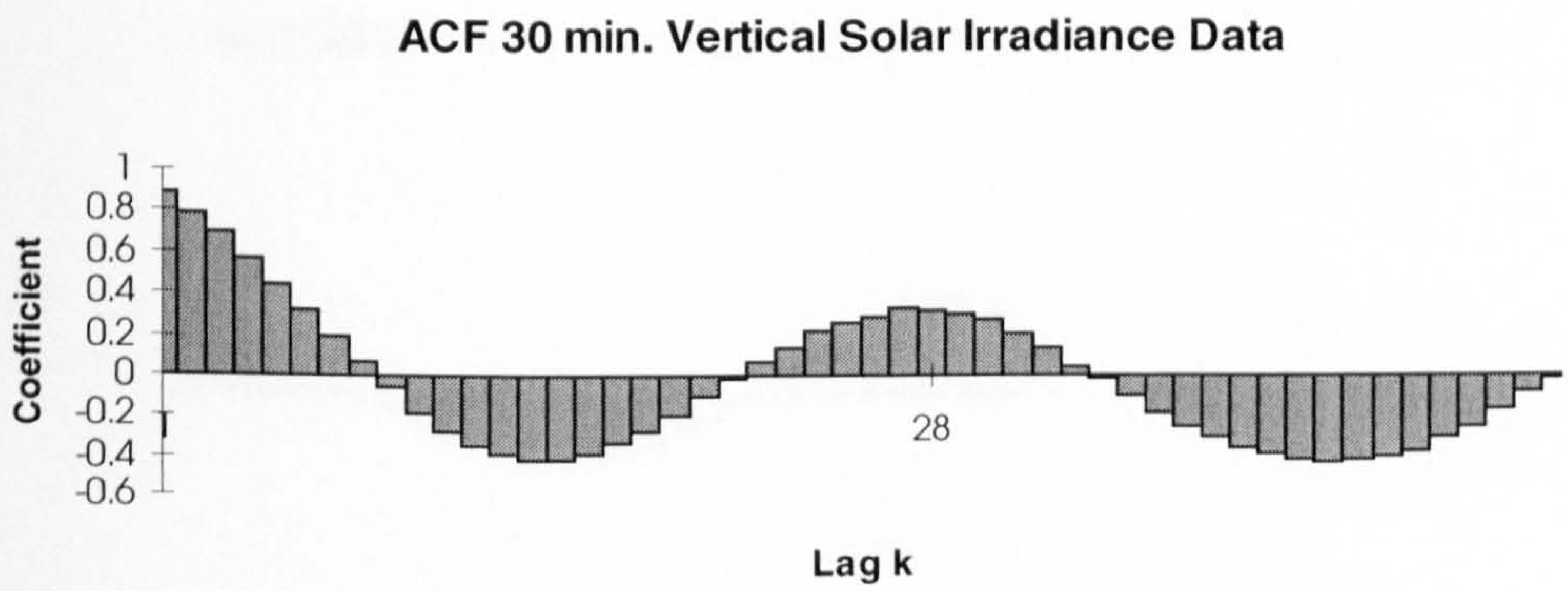


Figure 4.11.3 Vertical Solar Irradiance - 30 minute averages, JUN94_30

a)



b)



c)

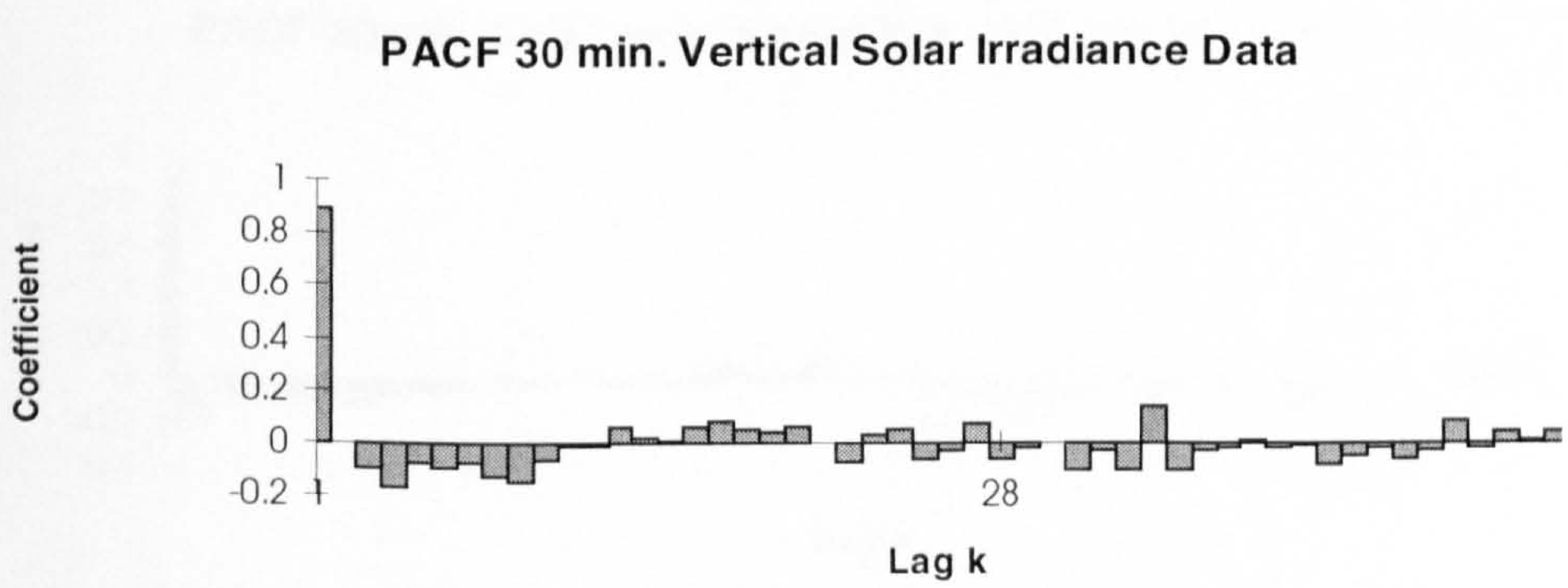
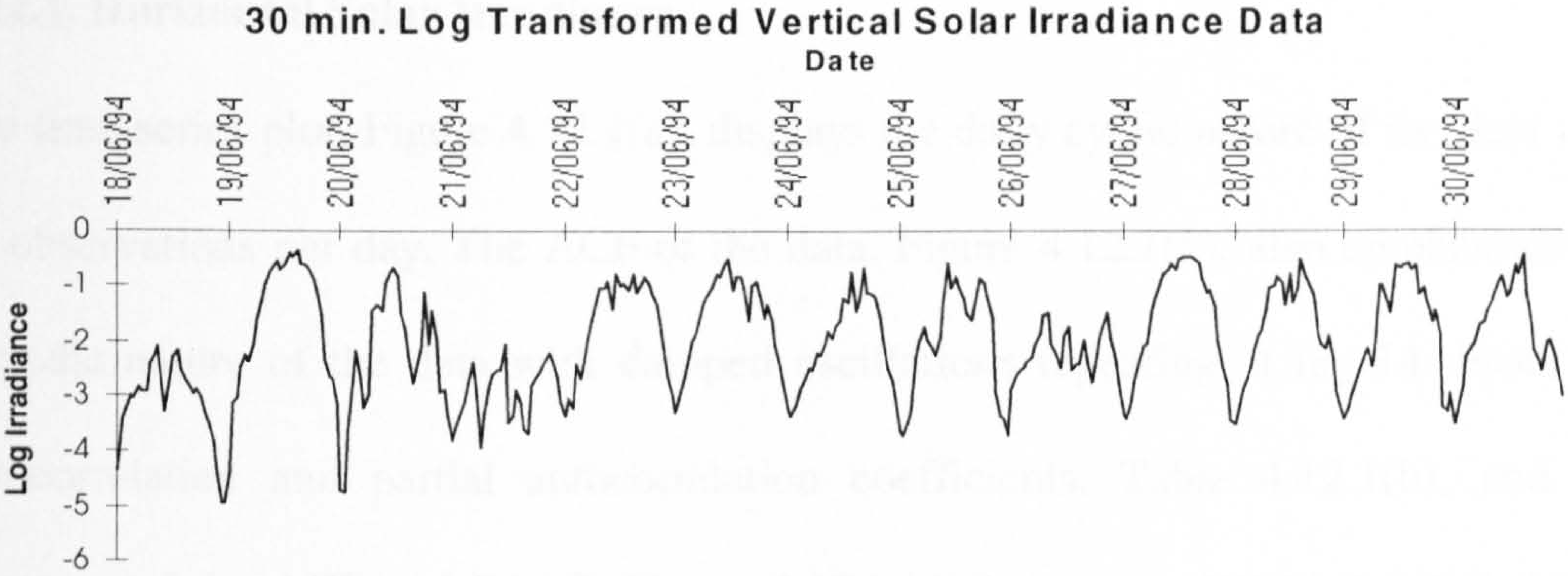
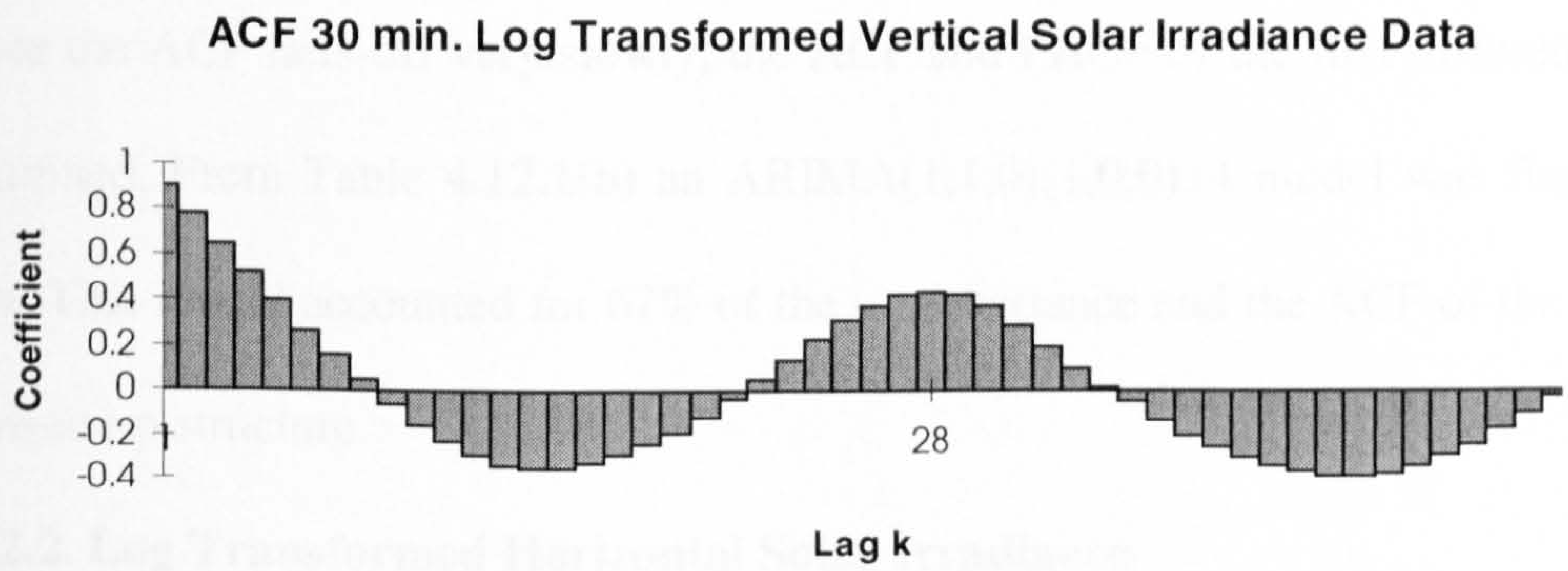


Figure 4.11.4 Log transformed Vertical Solar Irradiance - 30 minute averages, JUN94_30

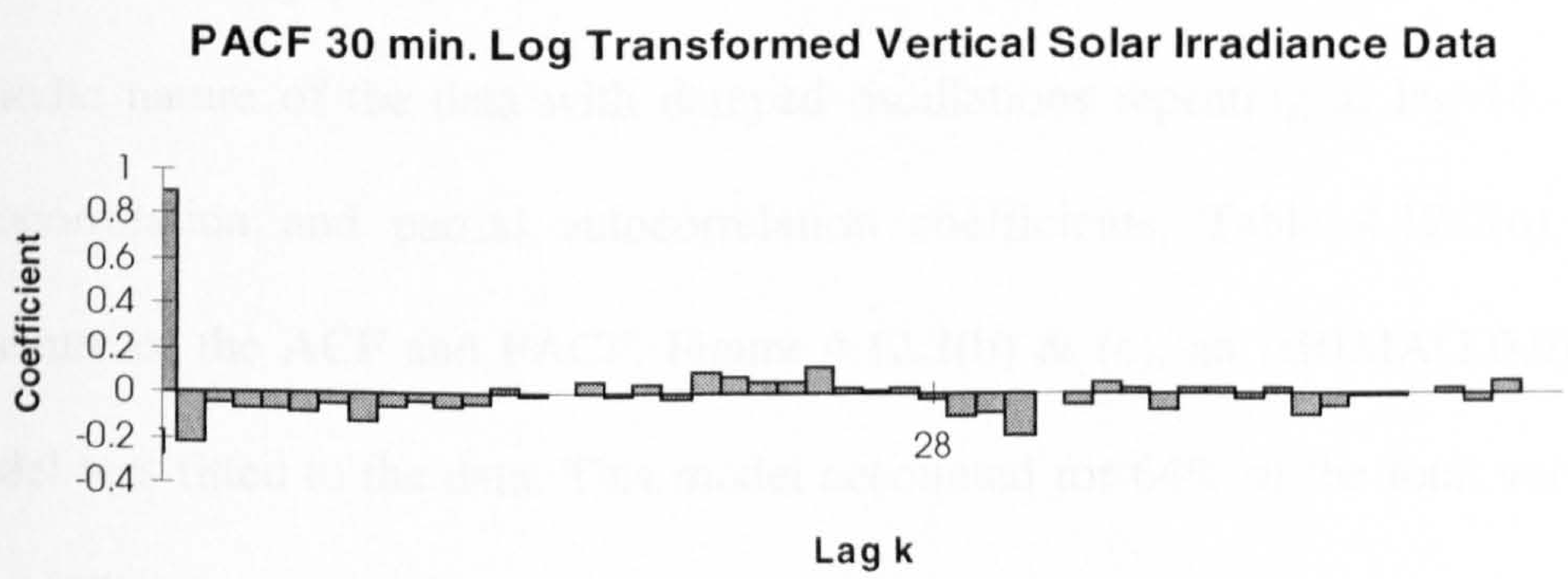
a)



b)



c)



4.12. June 1994 (18th - 30th) - Sixty minute averages

This data set, known as JUN94_60(18th-30th), contains 60 minute averaged Solar Irradiance data recorded between 18th and 30th June 1994.

4.12.1. Horizontal Solar Irradiance

The time series plot, Figure 4.12.1(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.12.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.12.1(b), and the structure of the ACF and PACF, Figure 4.12.1(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model accounted for 70% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.12.1(b) an ARIMA(1,1,0)(1,0,0)14 model was fitted to the data. This model accounted for 67% of the total variance and the ACF of the residuals showed no structure.

4.12.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.12.2(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.12.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.12.2(b), and the structure of the ACF and PACF, Figure 4.12.2(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model accounted for 64% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.12.2(b) an ARIMA(1,1,0)(1,0,0)14 model was fitted to the data. This model also accounted for 58% of the total variance and the ACF of the residuals showed no structure.

4.12.3. Vertical Solar Irradiance

The time series plot, Figure 4.12.3(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.12.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.12.3(b), and the structure of the ACF and PACF, Figure 4.12.3(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model accounted for 76% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.12.3(b) an ARIMA(1,1,0)(1,0,0)14 model was fitted to the data. This model accounted for 75% of the total variance and the ACF of the residuals showed no structure.

4.12.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.12.4(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.12.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.12.4(b), and the structure of the ACF and PACF, Figure 4.12.4(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model accounted for 73% of the total variance but the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.12.4(b) an ARIMA(1,1,0)(1,0,0)14 model was fitted to the data. This model accounted for 70% of the total variance and the ACF of the residuals showed no structure.

Table 4.12.1 Summary information for Horizontal Solar Irradiance - 60 minute averages (datafile JUN94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.3609	0.2330	0.0148	0.9140

b)

$2/\sqrt{182} = 0.148$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.820	0.820	0.174	0.174
2	0.581	-0.277	-0.036	-0.068
3	0.354	-0.089	-0.020	-0.002
4	0.134	-0.161	-0.009	-0.007
14	0.287	-0.08	0.252	0.087

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)14	AR1	0.8235	0.0429	19.18	2.87332	0.01605	70
	SAR14	0.2930	0.0751	3.90			
	CONST	0.0431	0.00941	4.58			
ARIMA(1,1,0)(1,0,0)14	AR1	0.0955	0.0753	1.27	3.14738	0.01758	67
	SAR14	0.2497	0.0774	3.23			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.2813	0.0756	3.72	3.17302	0.01763	67

Table 4.12.2 Summary information for Log Transformed Horizontal Solar Irradiance - 60 minute averages (datafile JUN94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.2896	0.8194	-4.2098	-0.0899

b)

$2/\sqrt{182} = 0.148$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.747	0.747	0.051	0.051
2	0.486	-0.163	-0.135	-0.137
3	0.287	-0.030	-0.024	-0.010
4	0.100	-0.138	-0.056	-0.074
14	0.374	-0.007	0.300	0.143

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)14	AR1	0.7507	0.0500	15.00	43.0160	0.2403	64
	SAR14	0.3812	0.0695	5.48			
	CONST	-0.2094	0.03646	-5.74			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.3384	0.0714	4.74	50.6377	0.2813	58
ARIMA(1,1,0)(1,0,0)14	AR1	-0.0641	0.0749	-0.86	50.4262	0.2817	58
	SAR14	0.3581	0.0715	5.01			

Table 4.12.3 Summary information for Vertical Solar Irradiance - 60 minute averages (datafile JUN94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2002	0.1647	0.0072	0.6620

b)

$2/\sqrt{182} = 0.148$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.852	0.852	0.347	0.347
2	0.607	-0.434	0.071	-0.056
3	0.341	-0.136	0.008	0.002
4	0.073	-0.207	0.000	0.000
14	0.338	-0.021	0.296	0.014

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)14	AR1	0.8535	0.0395	21.61	1.16708	0.00652	76
	SAR14	0.3444	0.0748	4.60			
	CONST	0.01797	0.00600	2.99			
ARIMA(1,1,0)(1,0,0)14	AR1	0.2706	0.0730	3.71	1.18522	0.00662	75
	SAR14	0.2307	0.0790	2.92			

Table 4.12.4 Summary information for Log Transformed Vertical Solar Irradiance - 60 minute averages (datafile JUN94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0012	0.9530	-4.9291	-0.4124

b)

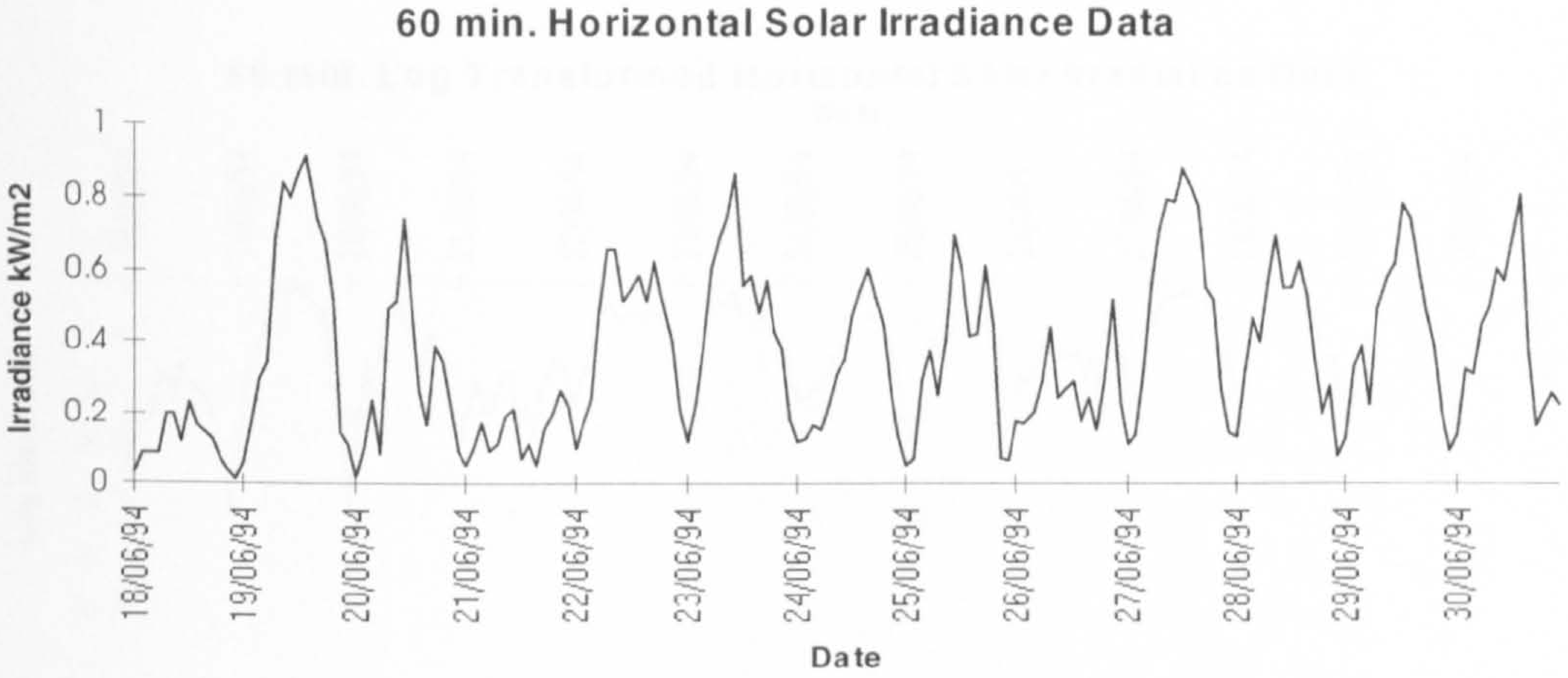
$2/\sqrt{182} = 0.148$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.808	0.808	0.218	0.218
2	0.547	-0.306	-0.013	-0.064
3	0.293	-0.120	-0.025	-0.008
4	0.047	-0.181	-0.080	-0.078
14	0.450	-0.031	0.386	0.189

c)

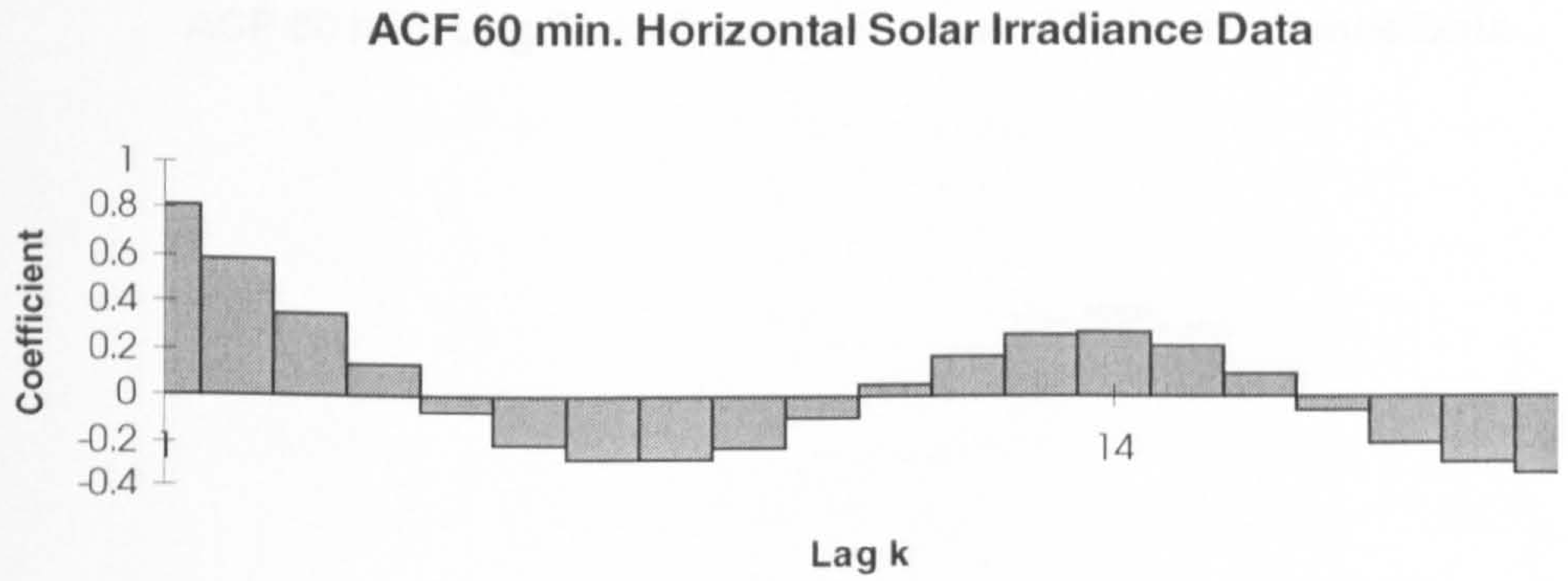
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)14	AR1	0.8043	0.0451	17.84	42.9201	0.2398	73
	SAR14	0.4691	0.0676	6.94			
	CONST	-0.2181	0.0365	-5.98			
ARIMA(1,1,0)(1,0,0)14	AR1	0.0309	0.0752	0.41	48.2144	0.2694	70
	SAR14	0.4359	0.0698	6.25			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.4484	0.0686	6.54	48.2282	0.2679	70

Figure 4.12.1 Horizontal Solar Irradiance - 60 minute averages, JUN94_60

a)



b)



c)

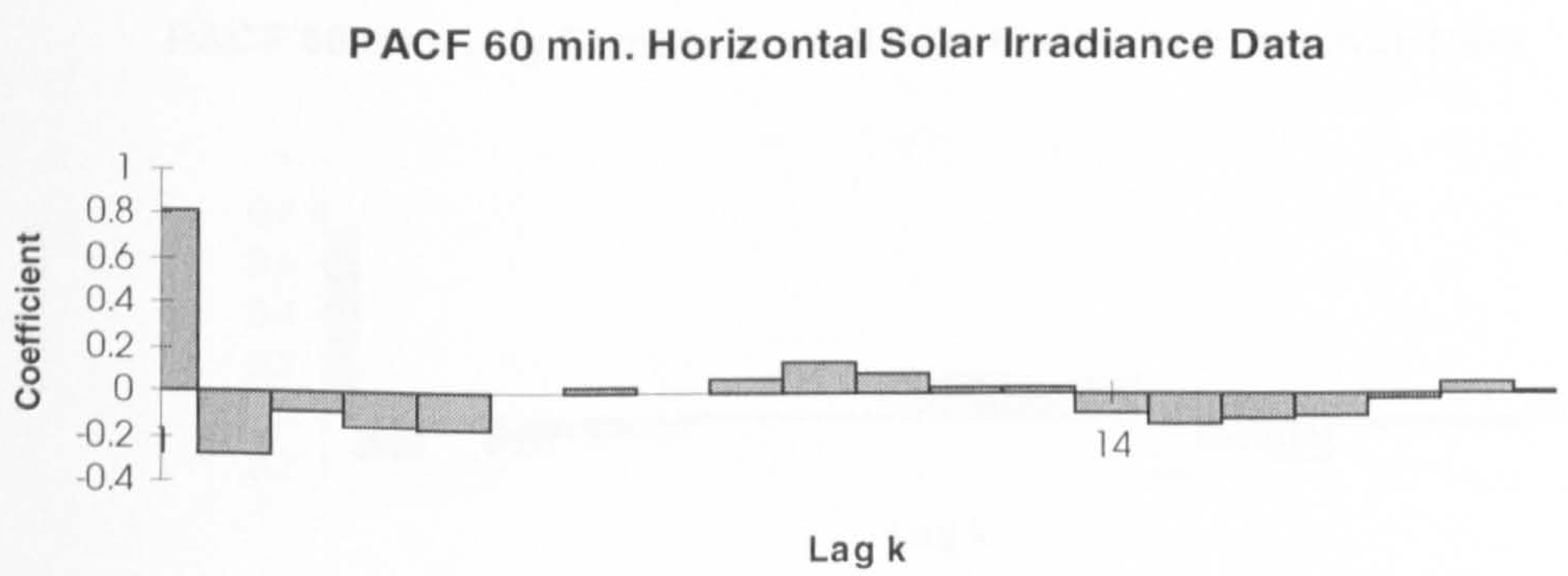
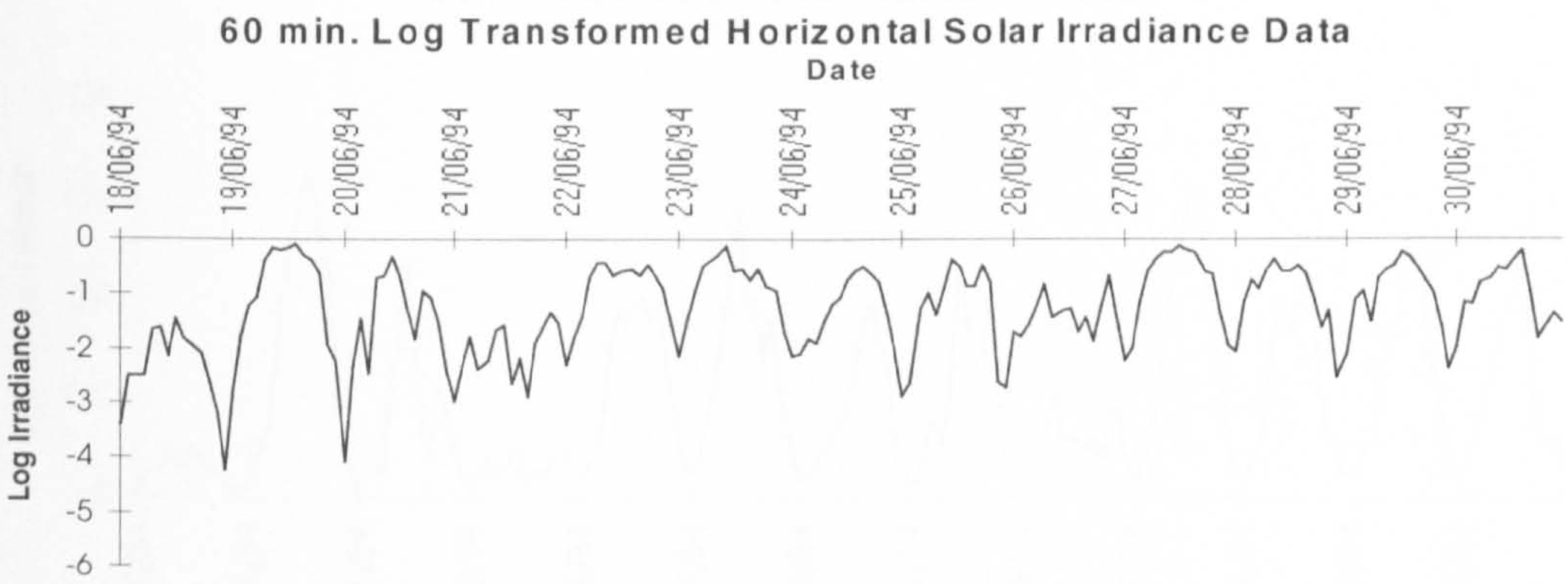
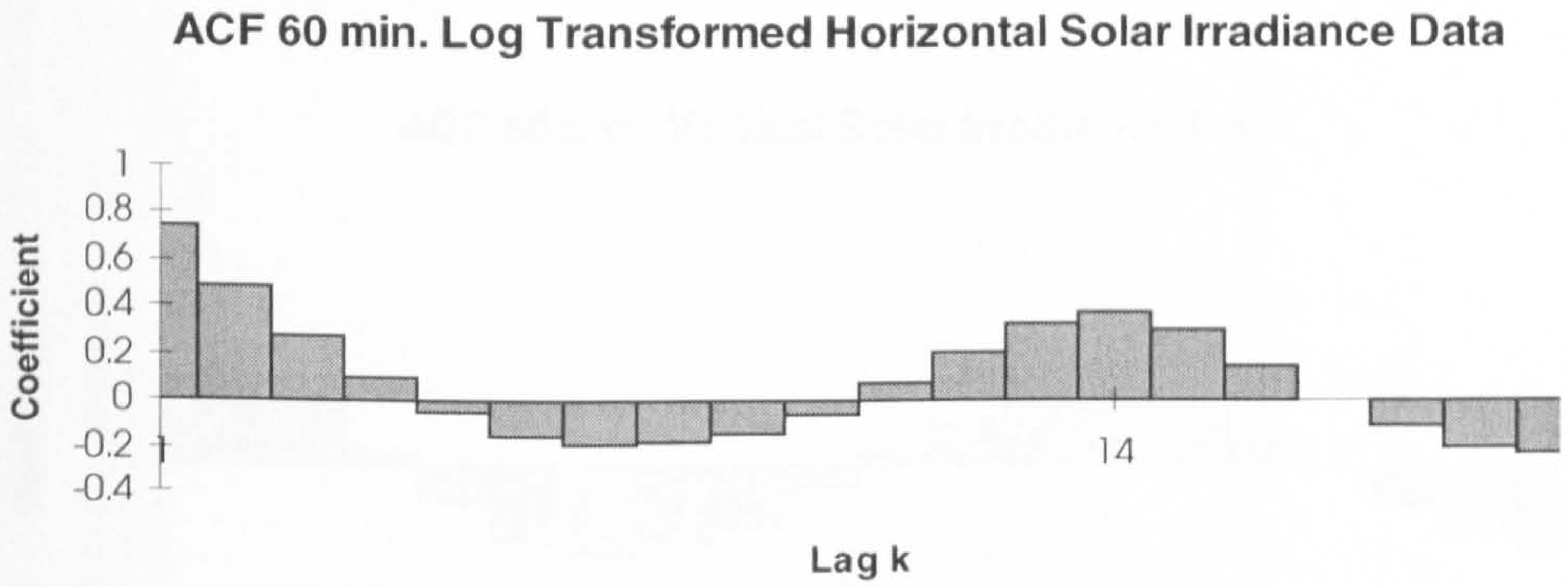


Figure 4.12.2 Log transformed Horizontal Solar Irradiance - 60 minute averages, JUN94_60

a)



b)



c)

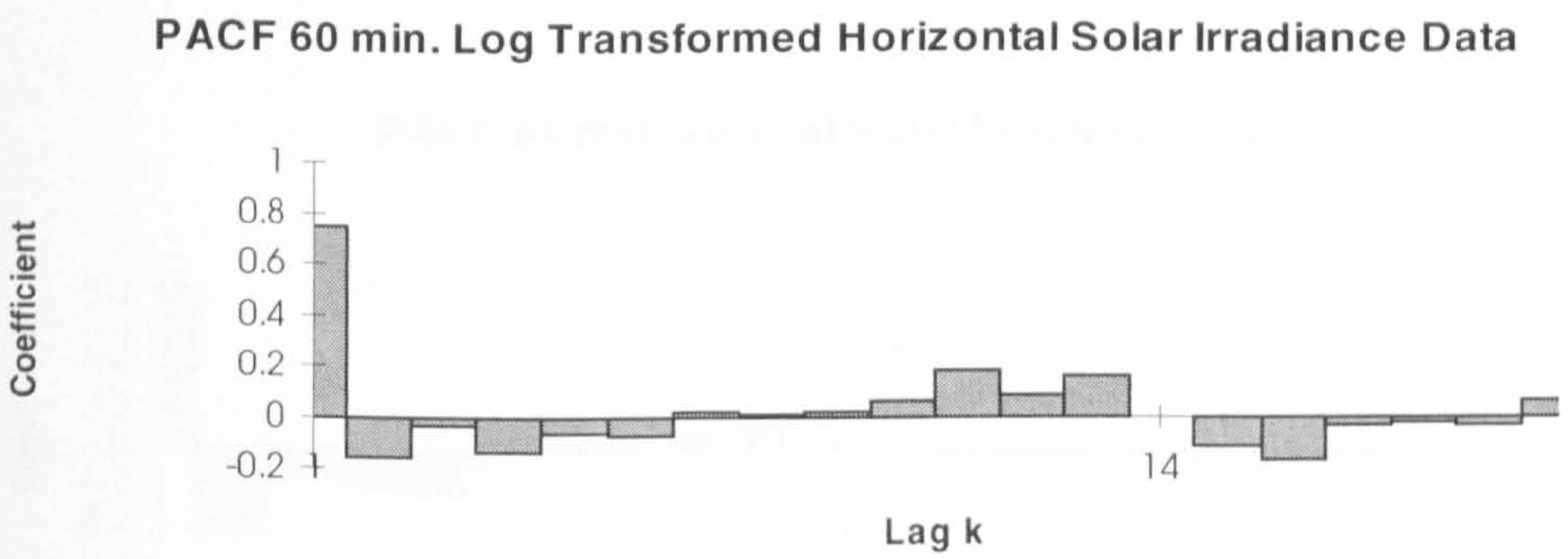
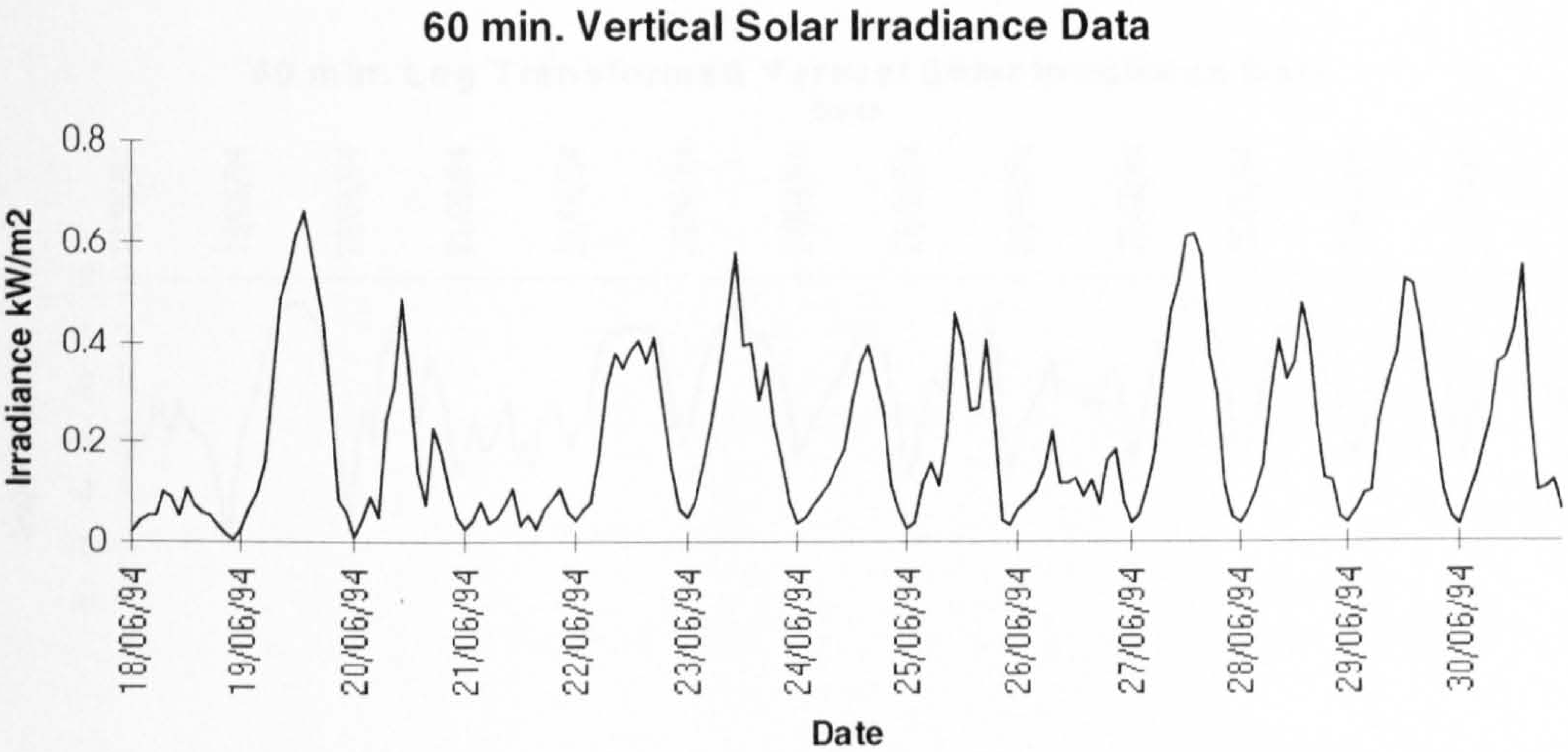
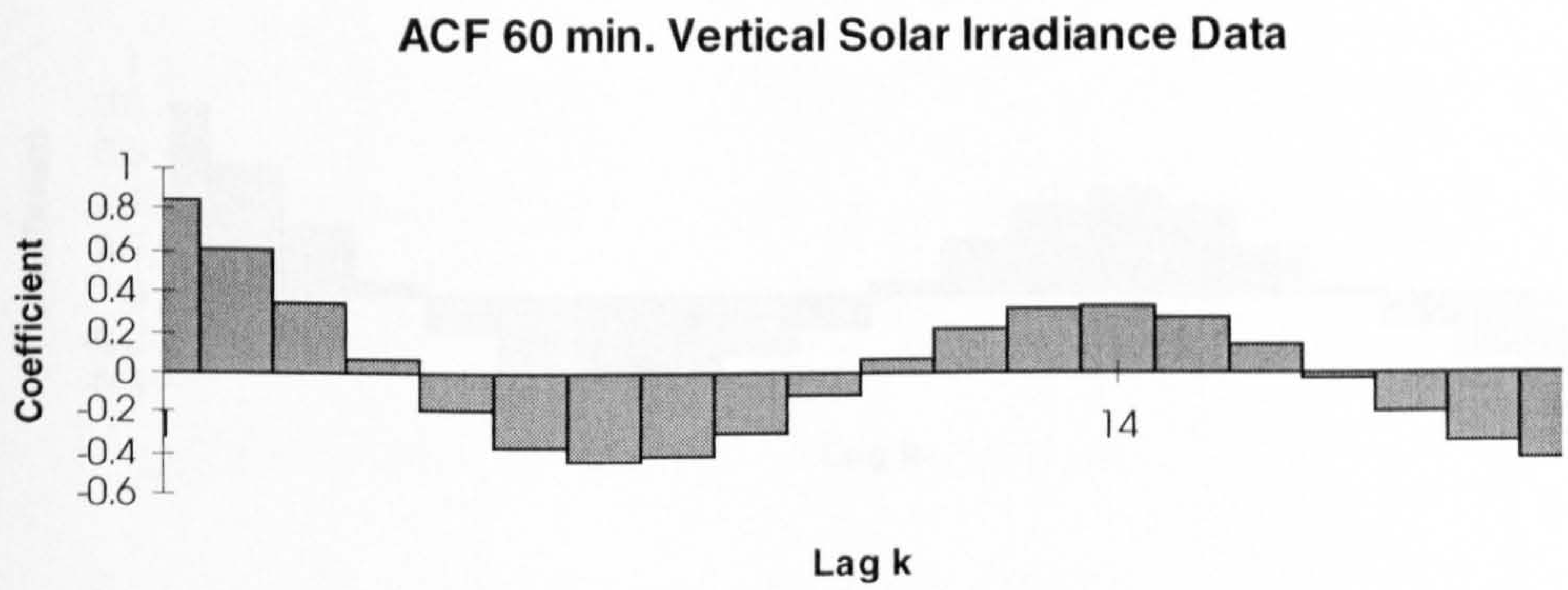


Figure 4.12.3 Vertical Solar Irradiance - 60 minute averages, JUN94_60

a)



b)



c)

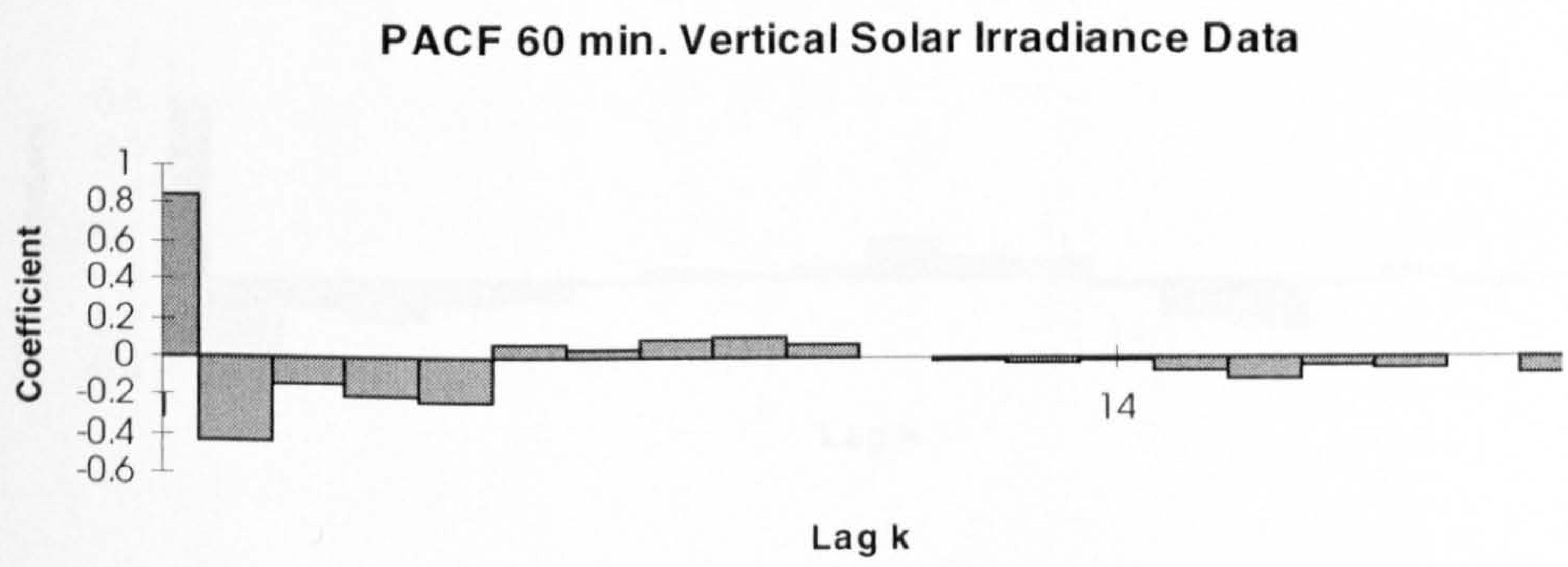
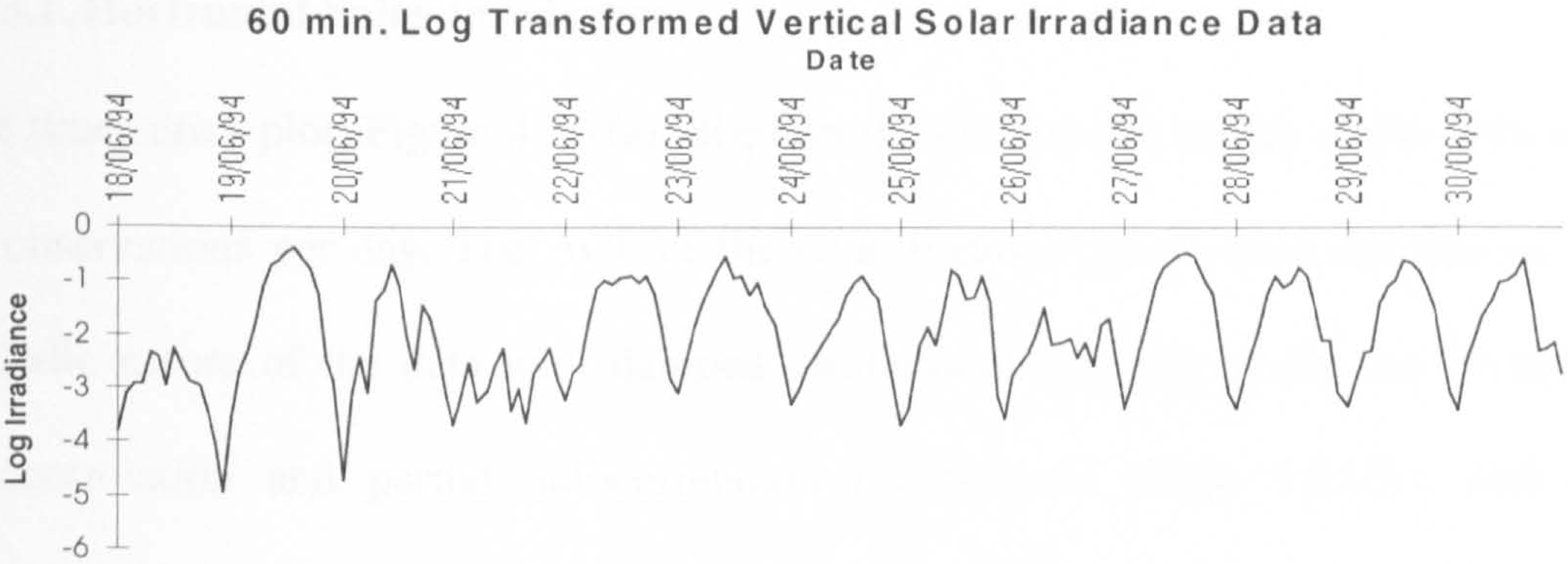
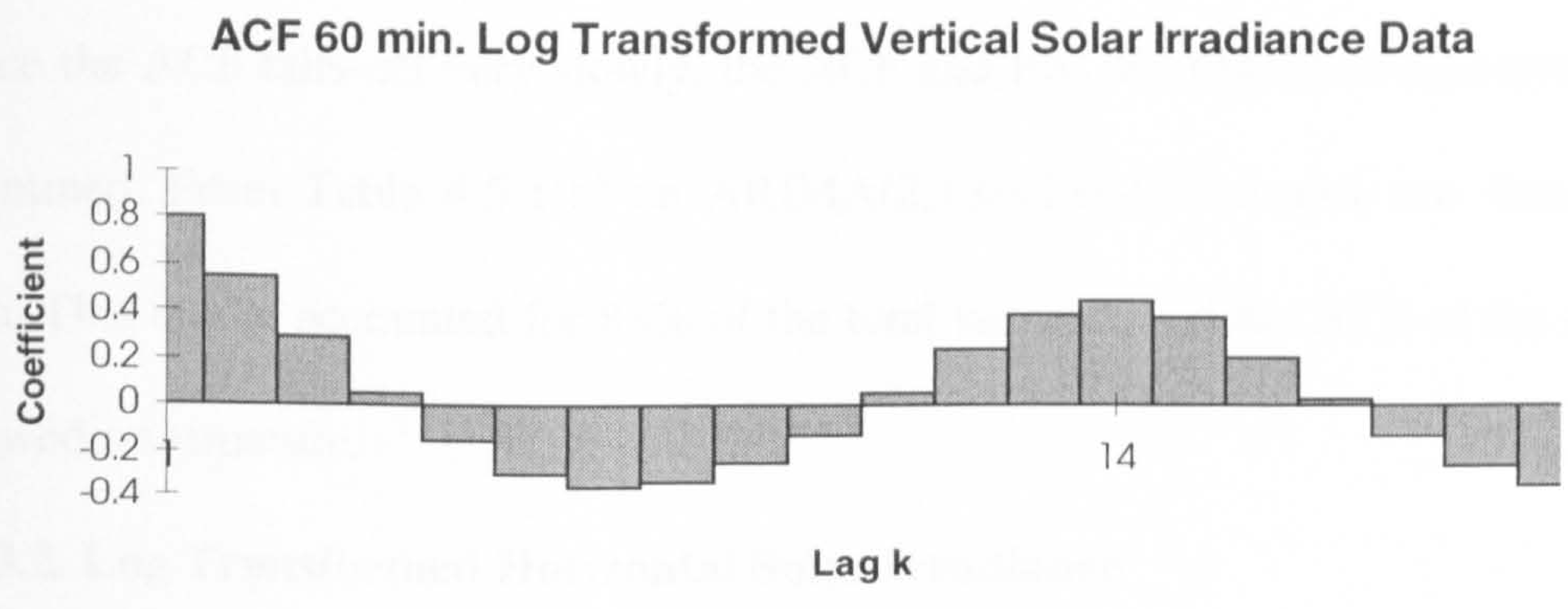


Figure 4.12.4 Log transformed Vertical Solar Irradiance - 60 minute averages, JUN94_60

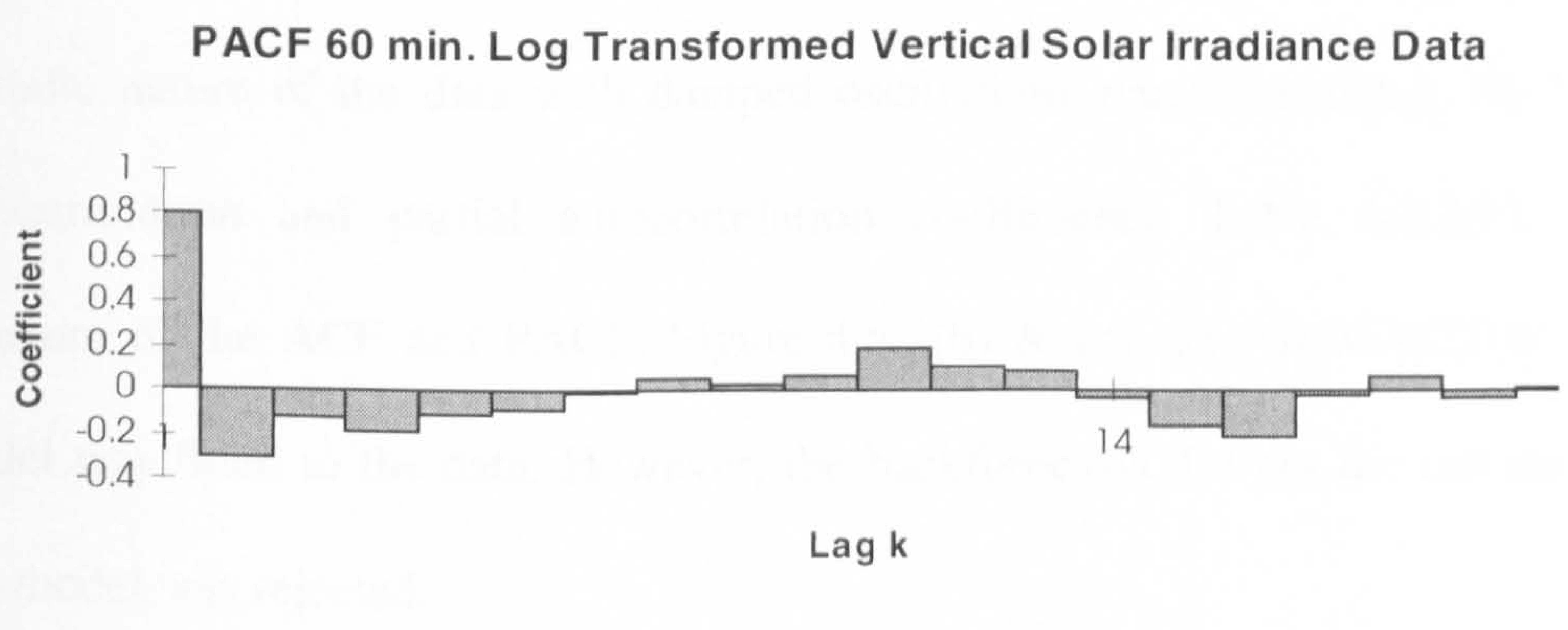
a)



b)



c)



4.13. December 1994 (1st - 15th) - Ten minute averages

This data set, known as DEC94_10, contains 10 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 1st and 15th December 1994.

4.13.1. Horizontal Solar Irradiance

The time series plot, Figure 4.5.1(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.5.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.5.1(b), and the structure of the ACF and PACF, Figure 4.5.1(b) & (c), an ARIMA(3,0,0)(1,0,0)36 model was fitted to the data. This model was found to be appropriate, accounted for 83% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.5.1(b) an ARIMA(2,1,0)(1,0,0)36 model was fitted to the data. This model accounted for 83% of the total variance and the ACF of the residuals showed no structure.

4.13.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.5.2(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.5.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.5.2(b), and the structure of the ACF and PACF, Figure 4.5.1(b) & (c), an ARIMA(2,0,0)(1,0,0)36 model was fitted to the data. However, the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.5.2(b) an ARIMA(2,1,0)(1,0,0)36 model was fitted to the data. This model accounted for 84% of the total variance and the ACF of the residuals showed no structure.

4.13.3. Vertical Solar Irradiance

The time series plot, Figure 4.5.3(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.5.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.5.3(b), and the structure of the ACF and PACF, Figure 4.5.3(b) & (c), an ARIMA(3,0,0)(1,0,0)36 model was fitted to the data. This model was found to be appropriate, accounted for 86% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.5.3(b) an ARIMA(2,1,0)(1,0,0)36 model was fitted to the data. This model accounted for 86% of the total variance and the ACF of the residuals showed no structure.

4.13.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.5.4(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.5.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.5.4(b), and the structure of the ACF and PACF, Figure 4.5.4(b) & (c), an ARIMA(3,0,0)(1,0,0)36 model was fitted to the data. However, the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.5.4(b) an ARIMA(3,1,0)(1,0,0)36 model was fitted to the data. This model accounted for 86% of the total variance and the ACF of the residuals showed no structure.

Table 4.13.1 Summary information for Horizontal Solar Irradiance - 10 minute averages (datafile DEC94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.06306	0.05166	0.0044	0.263

b)

$2/\sqrt{540} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.911	0.911	0.019	0.019
2	0.819	-0.065	-0.187	-0.187
3	0.759	0.142	-0.021	-0.014
4	0.704	-0.019	0.128	0.097
36	0.292	-0.001	0.010	-0.033

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(3,0,0)(1,0,0)36	AR1	0.9794	0.0428	22.89	0.23335	0.000436	83
	AR2	-0.2103	0.0594	-3.54			
	AR3	0.1521	0.0428	3.56			
	SAR36	0.0404	0.0437	0.92			
	CONST	0.00458	0.0089	5.09			
ARIMA(2,1,0)(1,0,0)36	AR1	0.0192	0.0424	0.45	2.41648	0.000451	83
	AR2	-0.192	0.0424	-4.53			
	SAR36	0.0353	0.0437	0.81			

Table 4.13.2 Summary information for Log Transformed Horizontal Solar Irradiance - 10 minute averages (datafile DEC94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.1449	0.9265	-5.4262	-1.3356

b)

$2/\sqrt{540} = 0.086$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.915	0.915	0.077	0.077
2	0.819	-0.111	-0.072	-0.078
3	0.735	0.025	-0.069	-0.058
4	0.664	0.023	0.013	0.017
36	0.364	-0.003	0.163	0.110

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,1,0)(1,0,0)36	AR1	0.0576	0.0431	1.34	71.5690	0.1335	84
	AR2	-0.0887	0.0430	-2.06			
	SAR36	0.1716	0.0437	3.92			

Table 4.13.3 Summary information for Vertical Solar Irradiance - 10 minute averages (datafile DEC94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.15658	0.21339	0.0024	0.7872

b)

$2/\sqrt{540} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.927	0.927	0.126	0.126
2	0.835	-0.168	-0.171	-0.190
3	0.768	0.145	-0.101	-0.054
4	0.715	0.020	0.029	0.020
36	0.014	0.001	0.012	-0.032

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(3,0,0)(1,0,0)36	AR1	1.1103	0.0427	25.97	3.26041	0.00609	86
	AR2	-0.3319	0.0626	-5.30			
	AR3	0.1503	0.0428	3.51			
	SAR36	0.0257	0.0433	0.59			
	CONST	0.01039	0.00336	3.09			
ARIMA(2,1,0)(1,0,0)36	AR1	0.1507	0.0424	3.55	3.37723	0.00630	86
	AR2	-0.1915	0.0424	-4.52			
	SAR36	0.0273	0.0432	0.63			

Table 4.13.4 Summary information for Log Transformed Vertical Solar Irradiance - 10 minute averages (datafile DEC94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0201	1.6533	-6.0323	-0.2393

b)

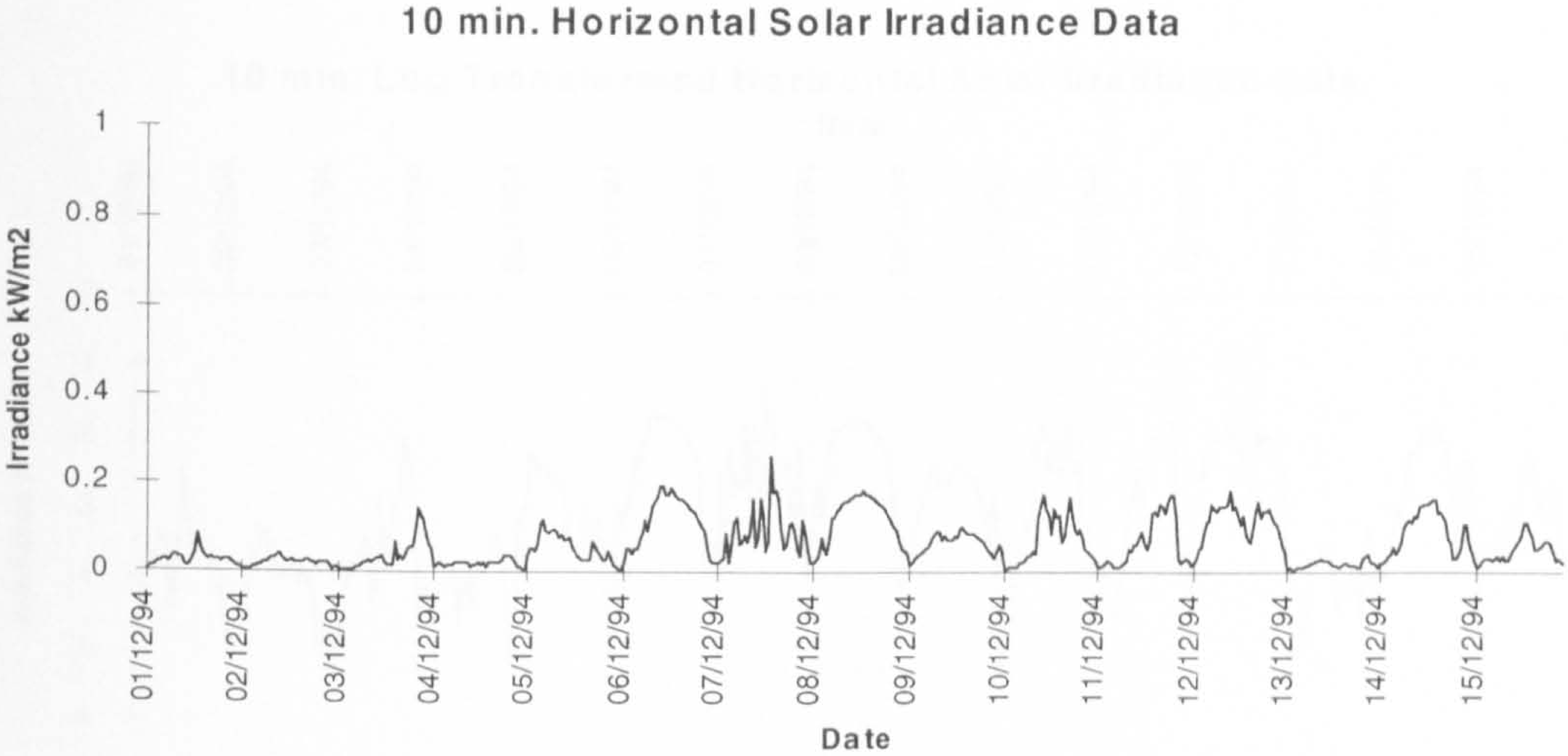
$2/\sqrt{540} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.923	0.923	0.089	0.089
2	0.832	-0.126	-0.136	-0.145
3	0.763	0.096	-0.111	-0.087
4	0.710	0.056	0.023	0.023
36	0.207	0.015	0.115	0.045

c)

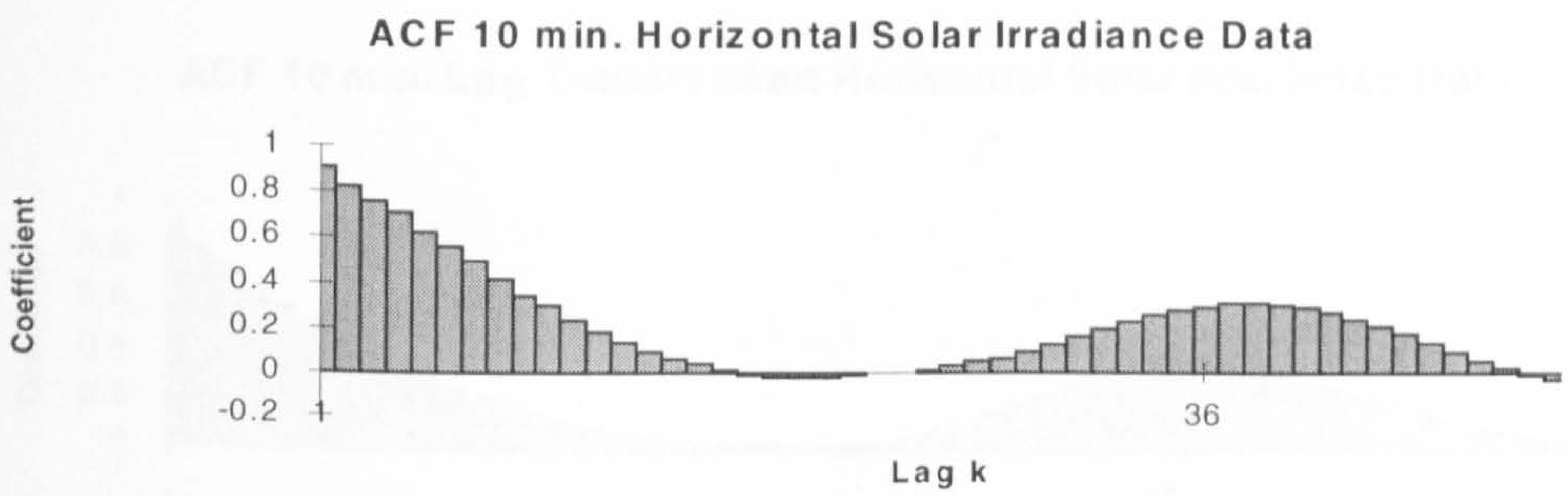
model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,1,0)(1,0,0)36	AR1	0.0977	0.0427	2.29	210.408	0.393	86
	AR2	-0.145	0.0428	-3.40			
	SAR36	0.116	0.0435	2.66			

Figure 4.13.1 Horizontal Solar Irradiance - 10 minute averages, DEC94_10

a)



b)



c)

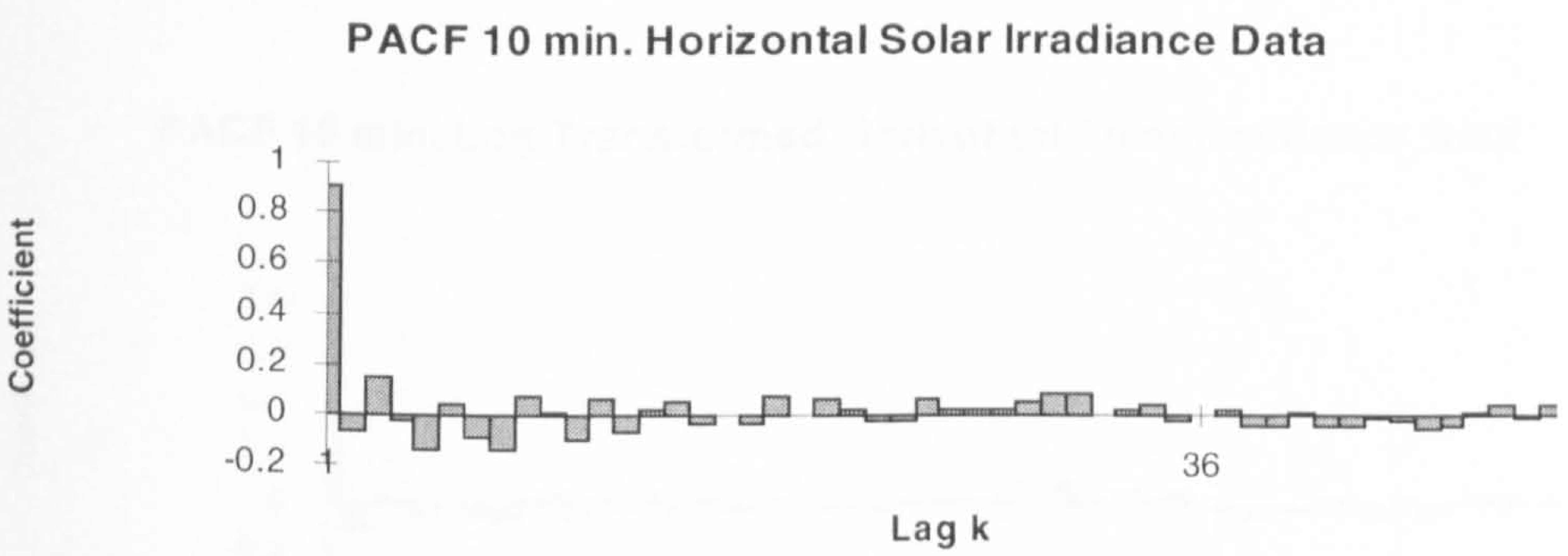
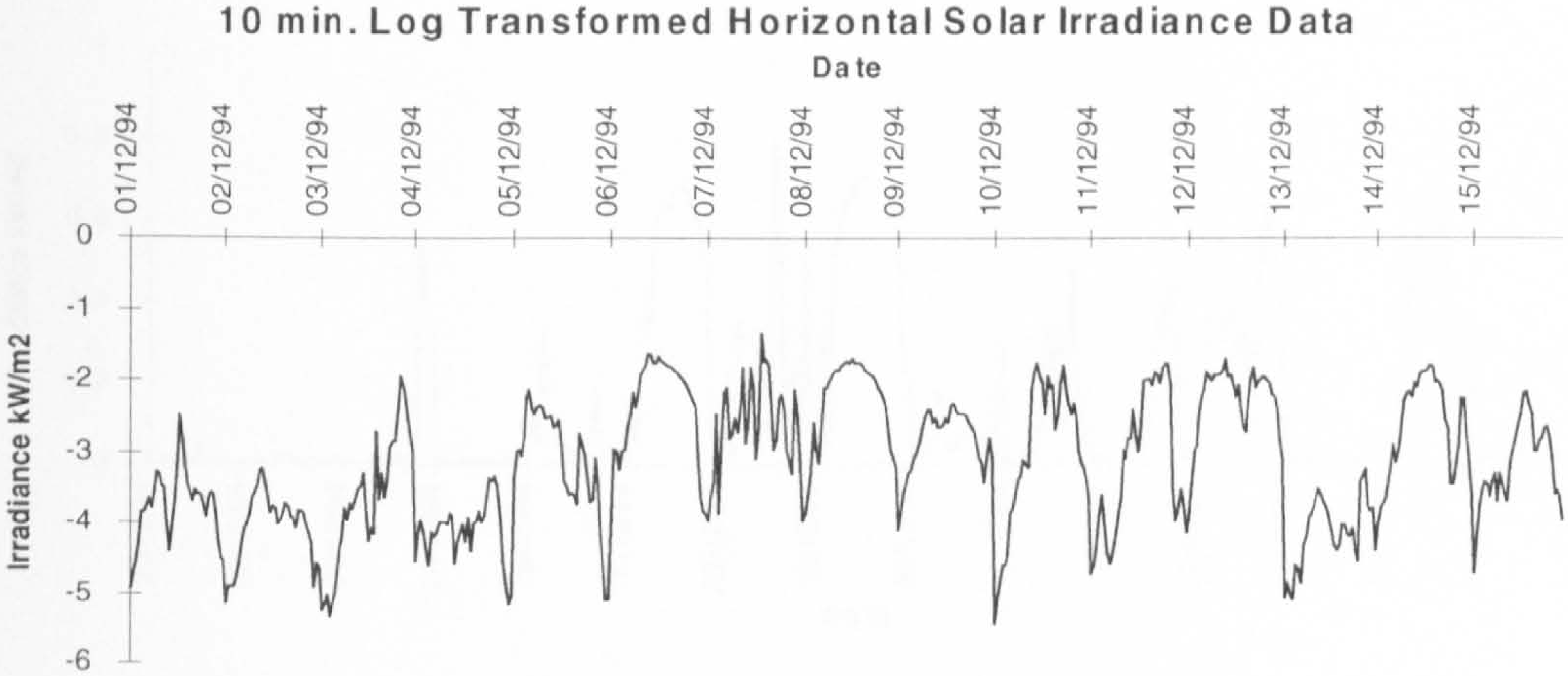
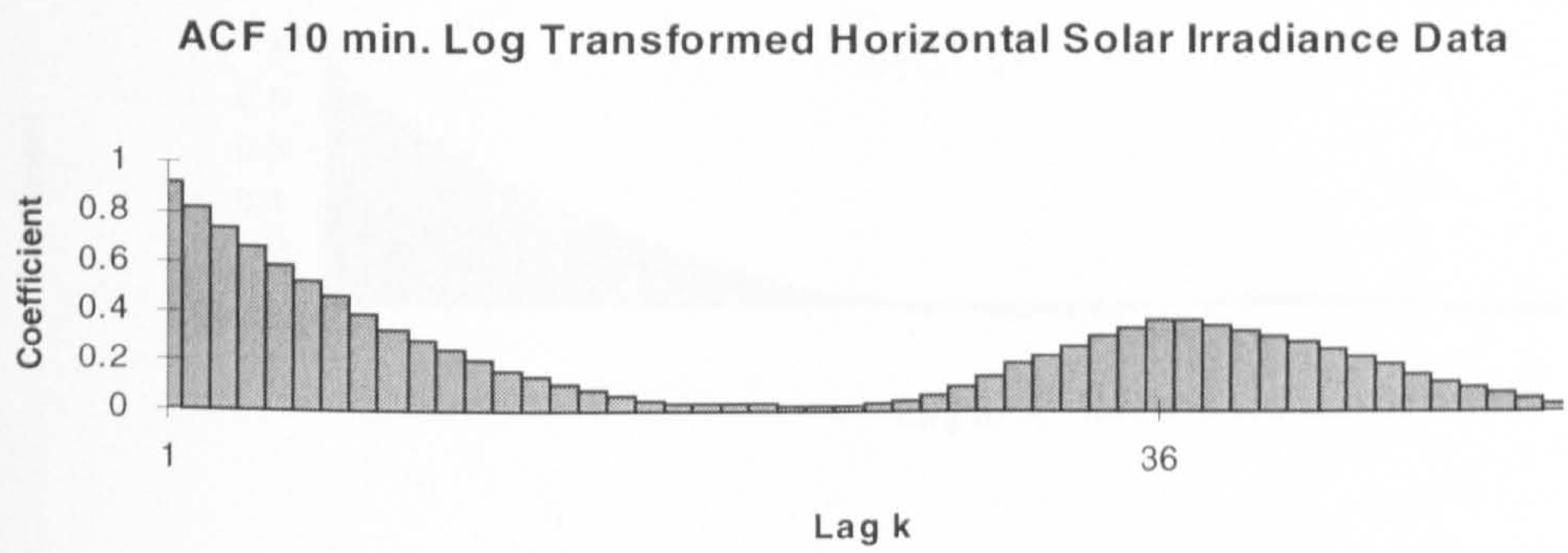


Figure 4.13.2 Log transformed Horizontal Solar Irradiance - 10 minute averages, DEC94_10

a)



b)



c)

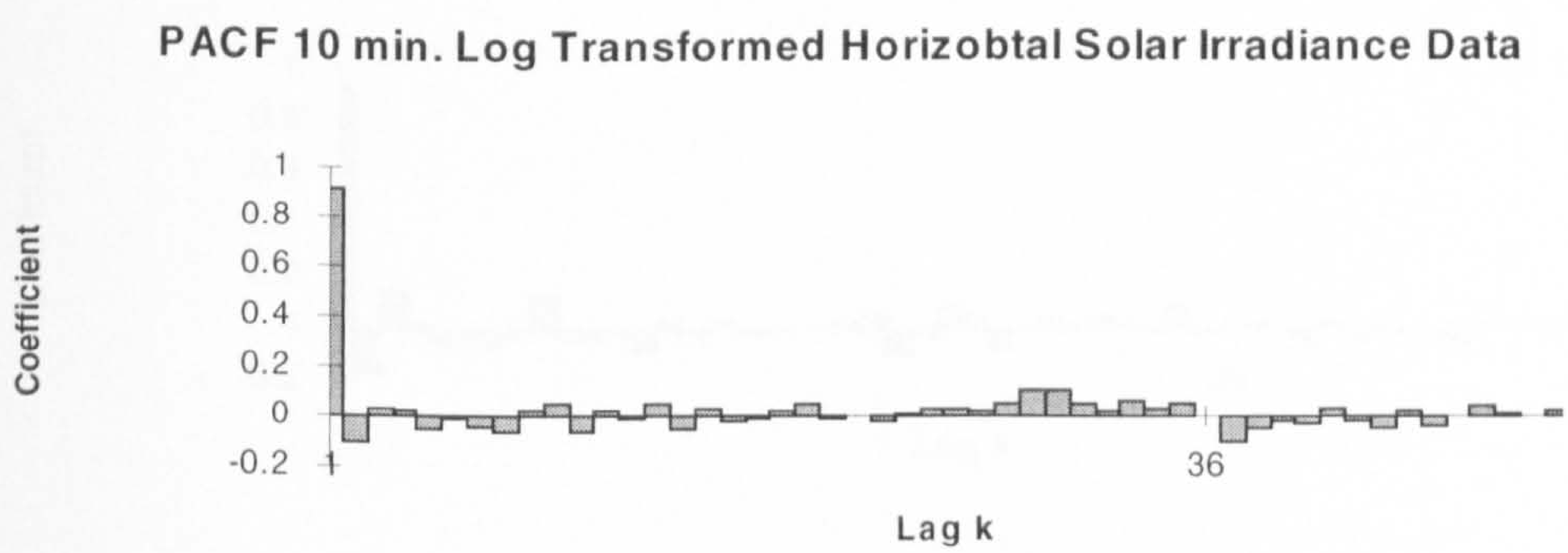
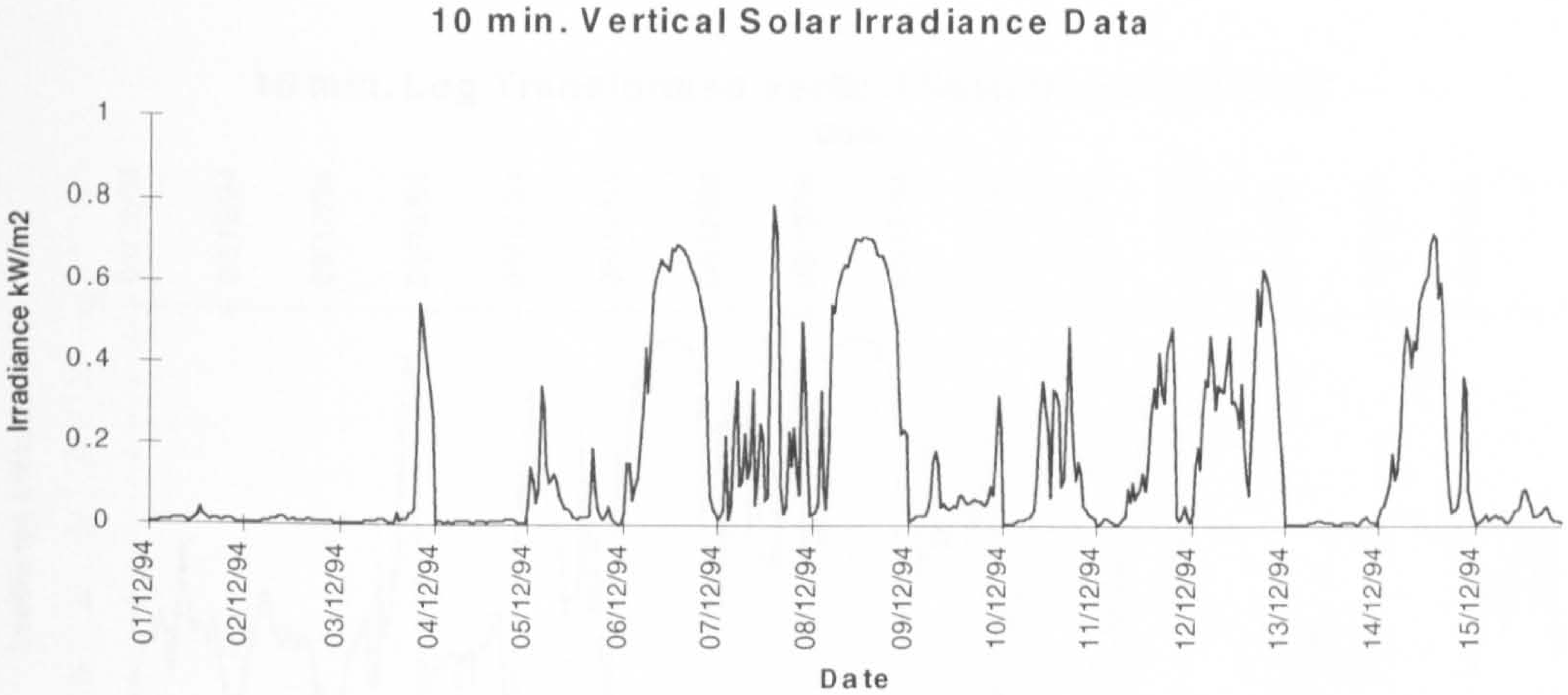
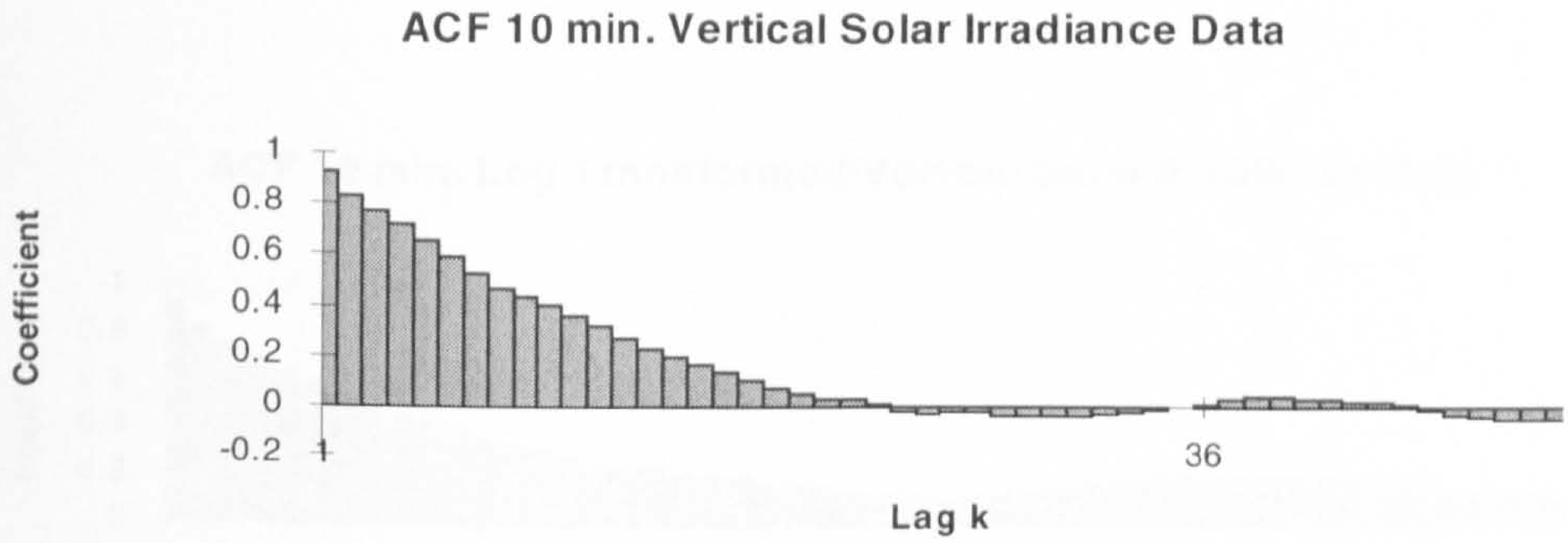


Figure 4.13.3 Vertical Solar Irradiance - 10 minute averages, DEC94_10

a)



b)



c)

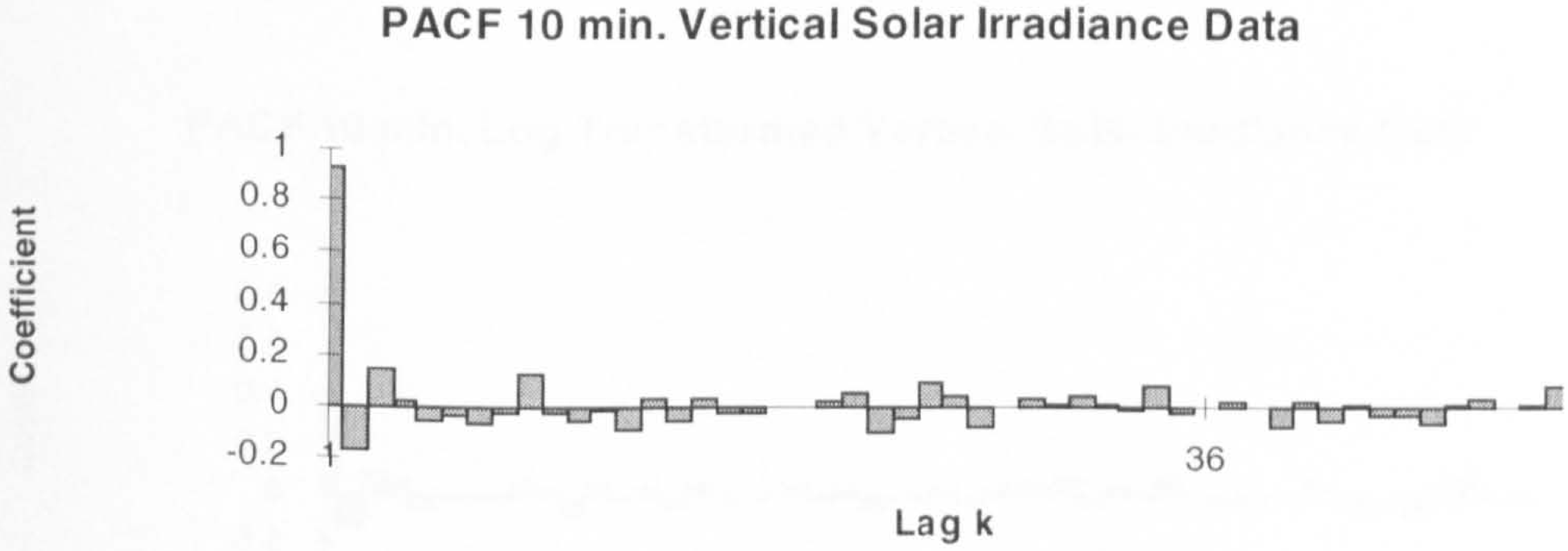
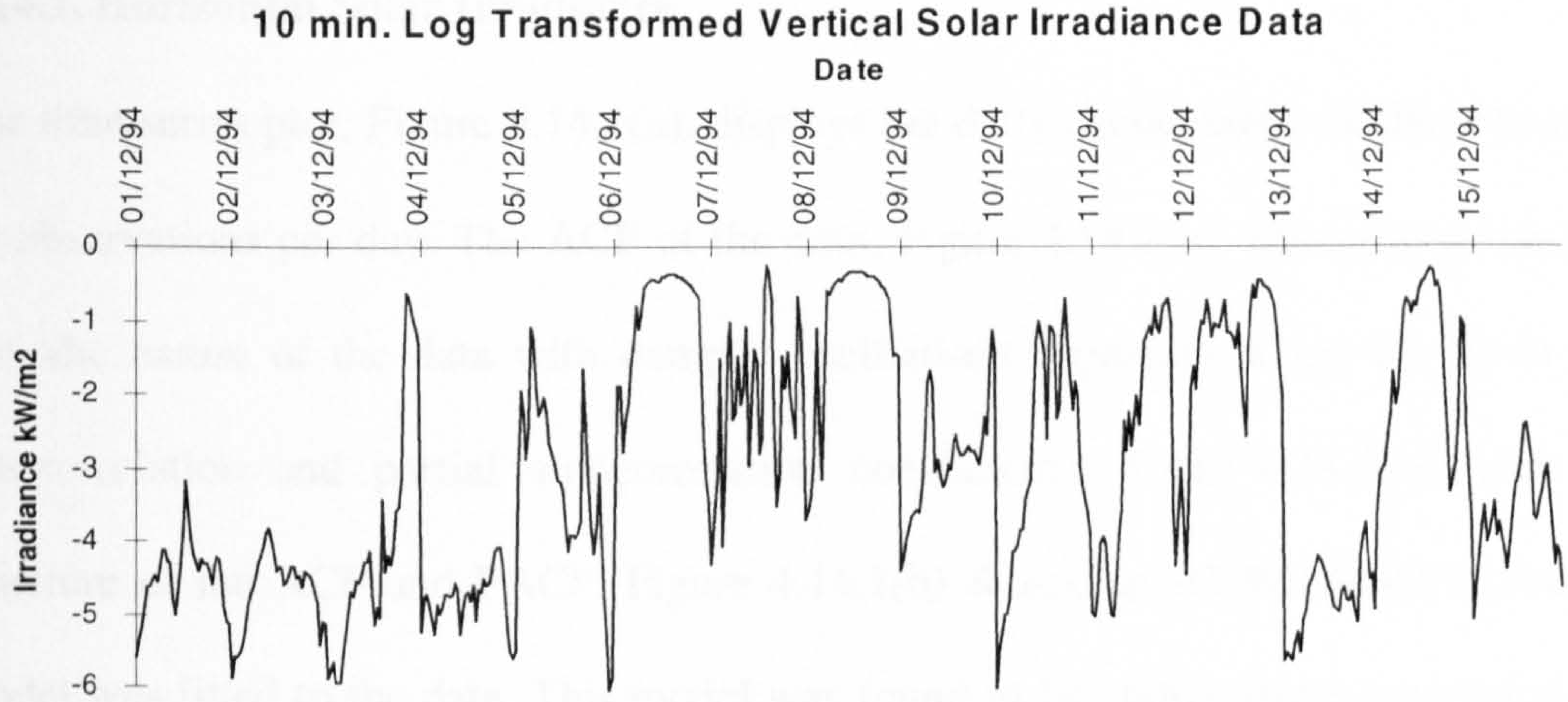
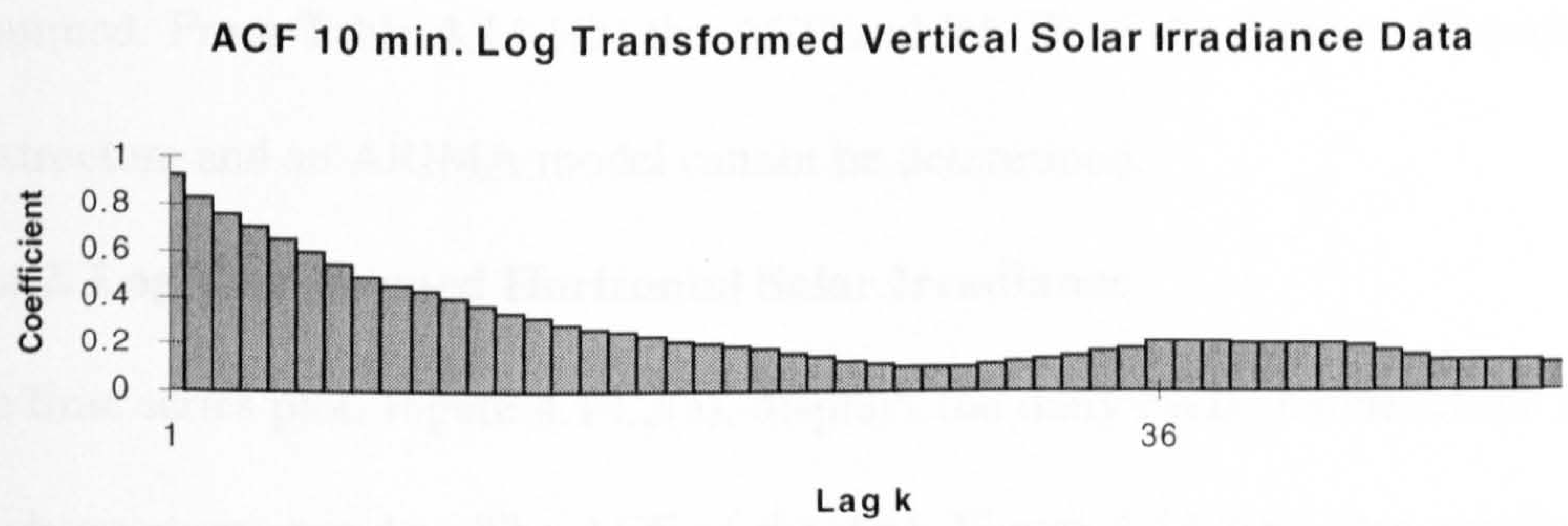


Figure 4.13.4 Log transformed Vertical Solar Irradiance - 10 minute averages, DEC94_10

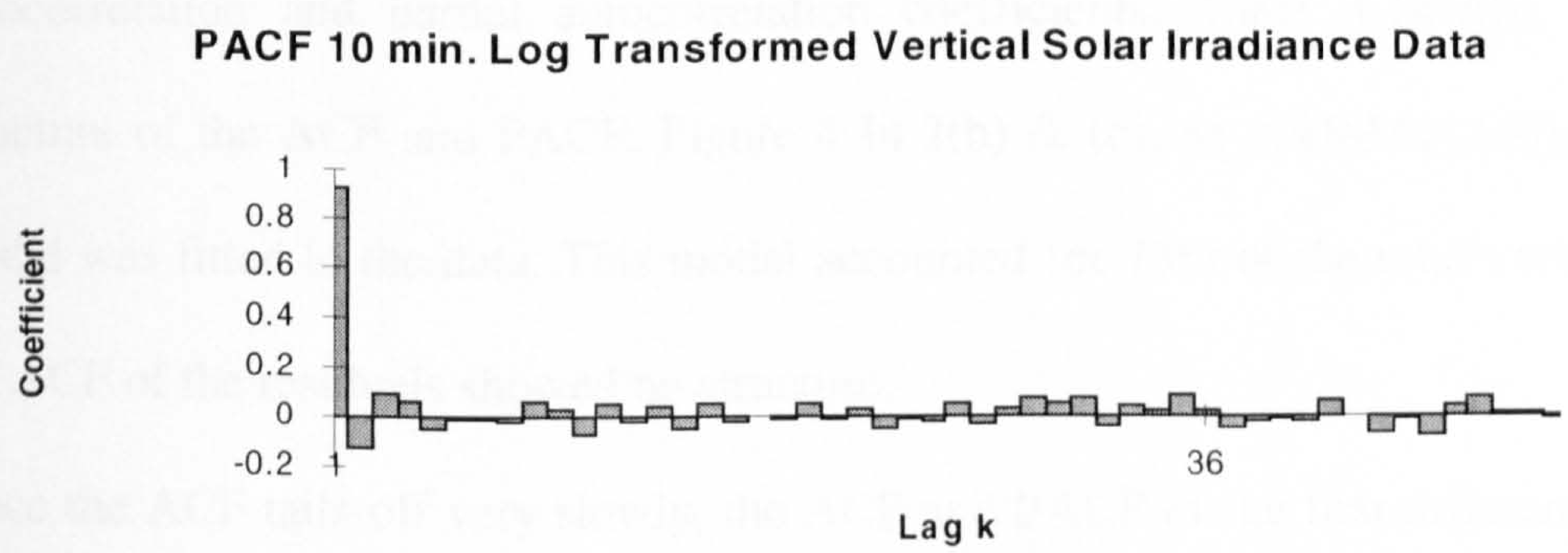
a)



b)



c)



4.14. December 1994 (1st - 15th) - Twenty minute averages

This data set, known as DEC94_20, contains 20 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 1st and 15th December 1994.

4.14.1. Horizontal Solar Irradiance

The time series plot, Figure 4.14.1(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.14.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.14.1(b), and the structure of the ACF and PACF, Figure 4.14.1(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model was found to be approproppriate, accounted for 72% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.14.1(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model cannot be determined.

4.14.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.14.2(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.14.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.14.2(b), and the structure of the ACF and PACF, Figure 4.14.2(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model accounted for 73% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.14.2(b) an ARIMA(0,1,0)(1,0,0)18 model was fitted to the

data. This model accounted for 71% of the total variance and the ACF of the residuals showed no structure.

4.14.3. Vertical Solar Irradiance

The time series plot, Figure 4.14.3(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.14.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.14.3(b), and the structure of the ACF and PACF, Figure 4.14.3(b) & (c), anARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model was found to be appropriate, accounted for 74% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.14.3(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model cannot be determined.

4.14.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.14.4(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.14.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.14.4(b), and the structure of the ACF and PACF, Figure 4.14.4(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model was found to be appropriate, accounted for 73% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.14.4(b) an ARIMA(0,1,0)(1,0,0)18 model was fitted to the

data. This model accounted for 72% of the total variance and the ACF of the residuals showed no structure.

Table 4.14.1 Summary information for Horizontal Solar Irradiance - 20 minute averages (datafile DEC94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.06306	0.05091	0.00545	0.22165

b)

$2/\sqrt{270} = 0.122$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.844	0.844	-0.112	-0.112
2	0.722	0.036	0.079	0.068
3	0.578	-0.140	0.028	0.044
4	0.427	-0.129	-0.105	-0.105
18	0.297	-0.028	0.062	-0.031

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)18	AR1	0.8429	0.0332	25.41	0.19499	0.00073	72
	SA18	0.0893	0.0618	1.44			
	CONST	0.0087	0.0017	5.29			

Table 4.14.2 Summary information for Log Transformed Horizontal Solar Irradiance - 20 minute averages (datafile DEC94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.1332	0.9128	-5.2121	-1.5067

b)

$2/\sqrt{270} = 0.122$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.838	0.838	-0.010	-0.010
2	0.684	-0.064	-0.026	-0.027
3	0.542	-0.048	0.004	0.004
4	0.403	-0.084	-0.110	-0.111
18	0.365	0.049	0.228	0.122

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)18	AR1	0.8368	0.0339	24.70	59.1330	0.2215	73
	SAR18	0.2737	0.0602	4.54			
	CONST	-0.378	0.0287	-13.20			
ARIMA(0,1,0)(1,0,0)18	SAR18	0.2530	0.0607	4.17	64.6903	0.2414	71

Table 4.14.3 Summary information for Vertical Solar Irradiance - 20 minute averages (datafile DEC94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1566	0.2105	0.0026	0.7140

b)

$2/\sqrt{270} = 0.122$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.862	0.862	-0.039	-0.039
2	0.735	-0.033	-0.026	-0.026
3	0.615	-0.044	0.021	0.019
4	0.489	-0.094	-0.199	-0.198
18	0.011	0.002	0.004	-0.047

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)18	AR1	0.8654	0.0308	28.06	3.01988	0.01131	74
	SAR18	0.0058	0.0613	0.09			
	CONST	0.02004	0.00647	3.09			

Table 4.14.4 Summary information for Log Transformed Vertical Solar Irradiance - 20 minute averages (datafile DEC94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.991	1.643	-5.952	-0.337

b)

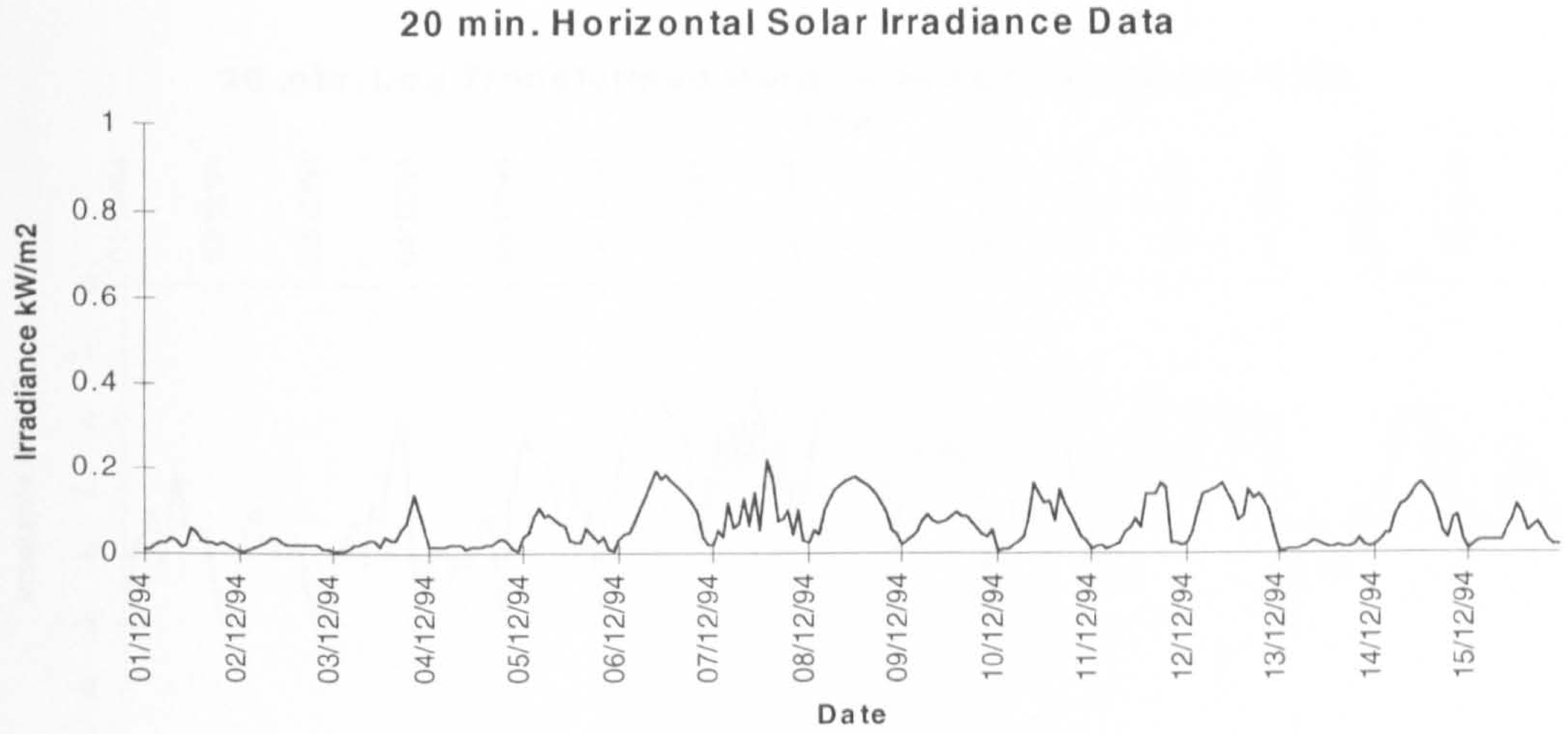
$2/\sqrt{270} = 0.122$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.851	0.851	-0.088	-0.088
2	0.728	0.016	-0.033	-0.041
3	0.616	-0.023	-0.019	-0.026
4	0.512	-0.036	-0.135	-0.142
18	0.205	0.111	0.122	0.033

c)

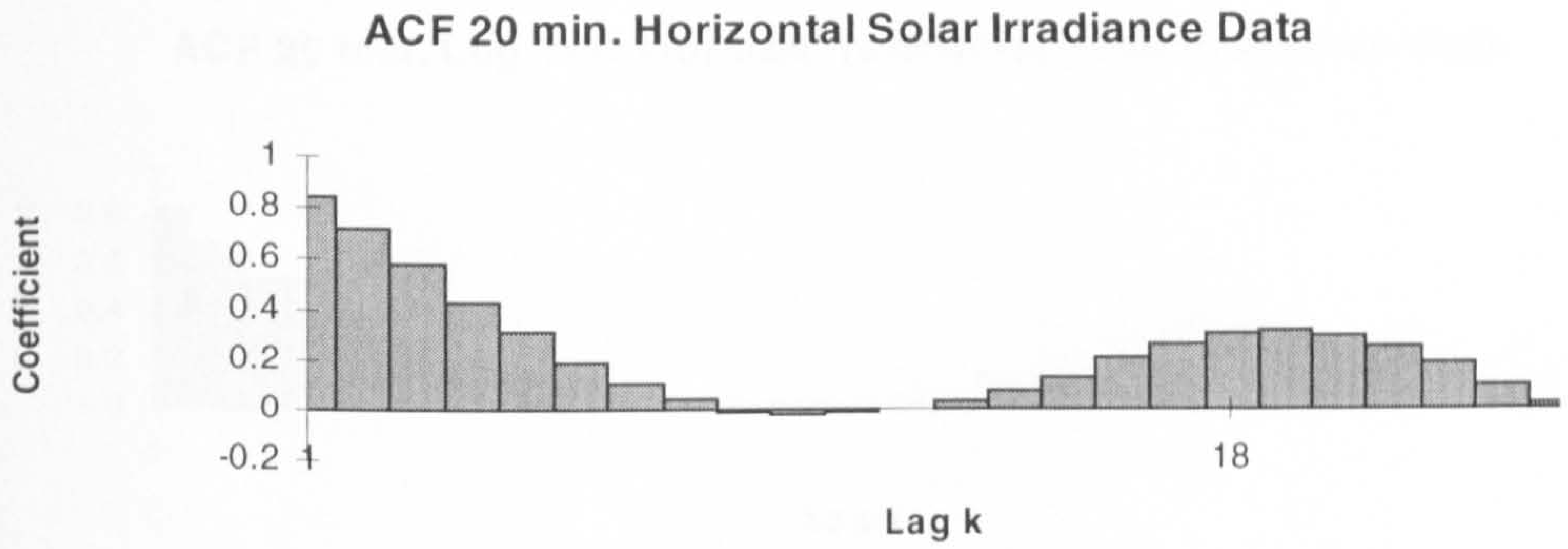
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)18	AR1	0.855	0.0321	26.69	190.219	0.712	73
	SAR18	0.1395	0.0614	2.27			
	CONST	-0.385	0.0515	-7.48			
ARIMA(0,1,0)(1,0,0)18	SAR18	0.1280	0.0615	2.08	205.676	0.767	72

Figure 4.14.1 Horizontal Solar Irradiance - 20 minute averages, DEC94_20

a)



b)



c)

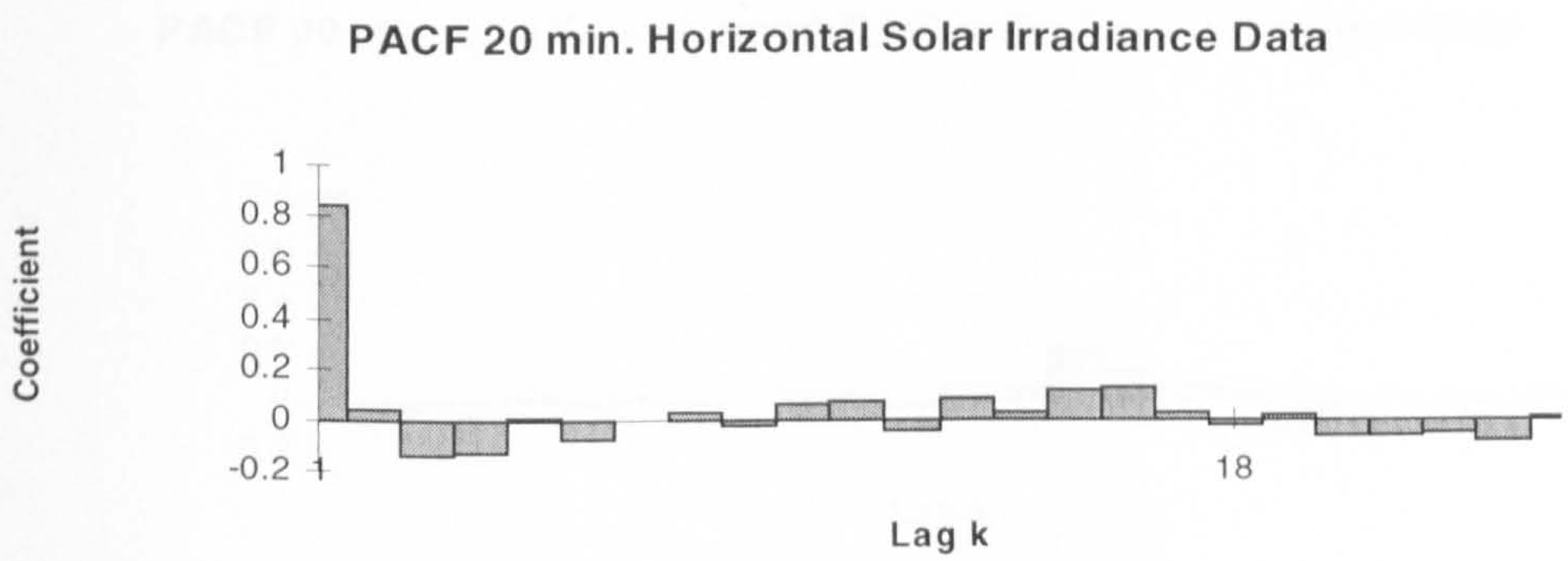
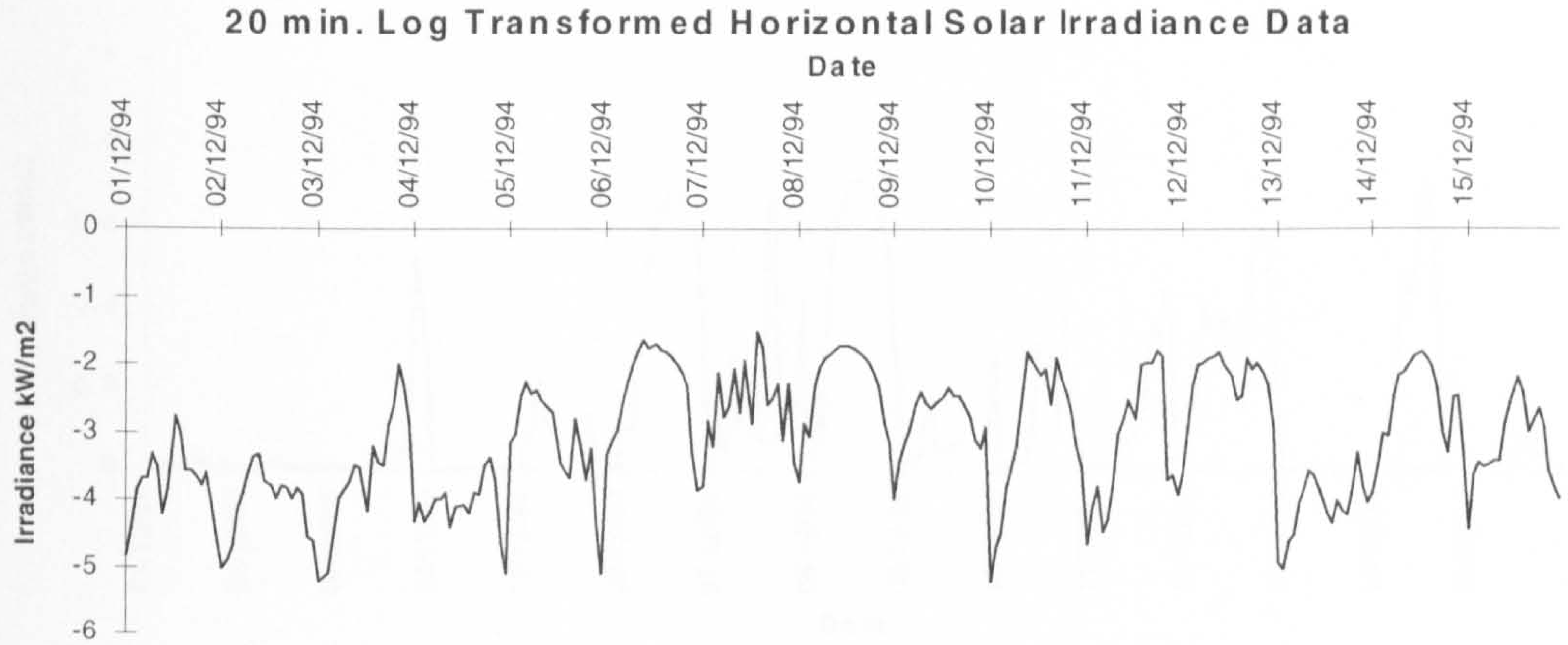
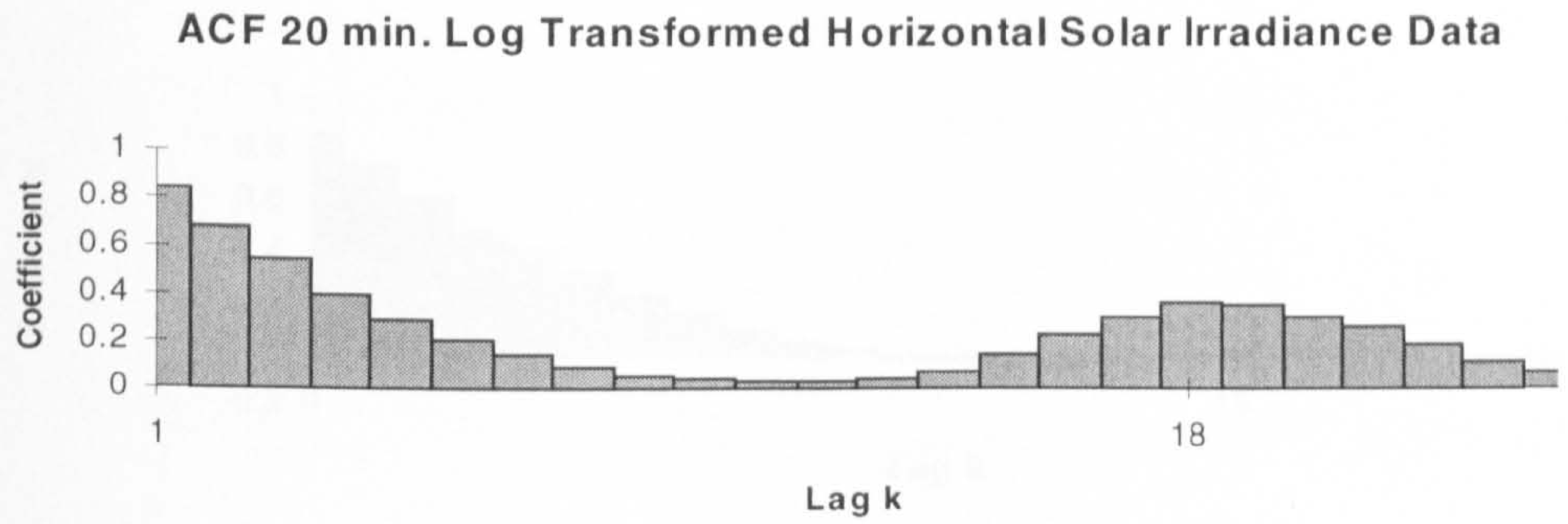


Figure 4.14.2 Log transformed Horizontal Solar Irradiance - 20 minute averages, DEC94_20

a)



b)



c)

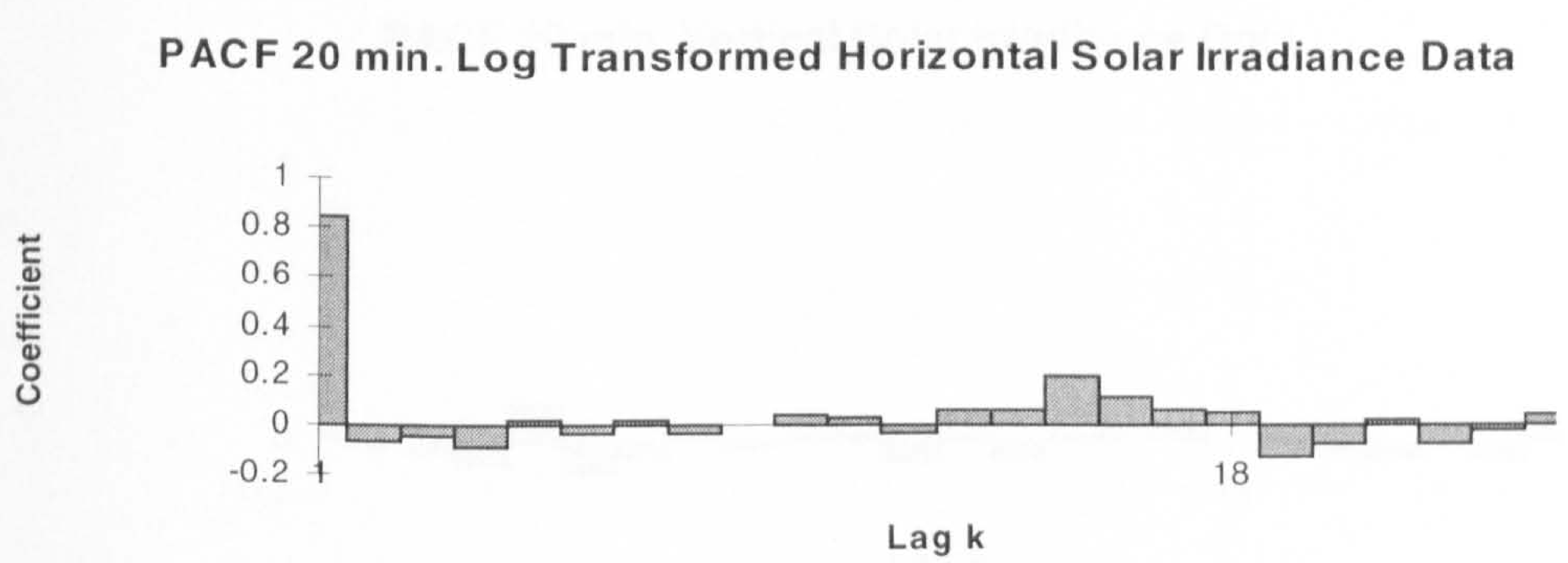
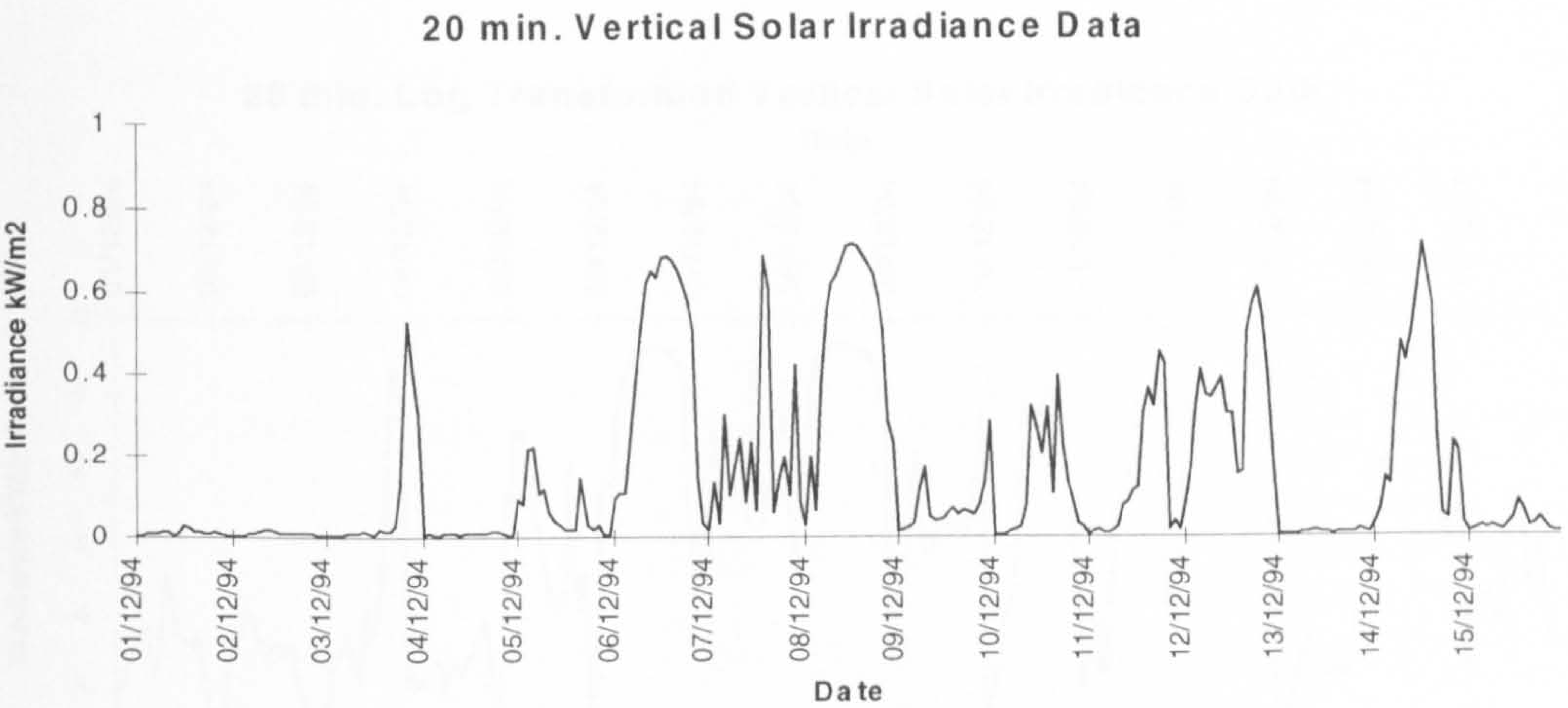
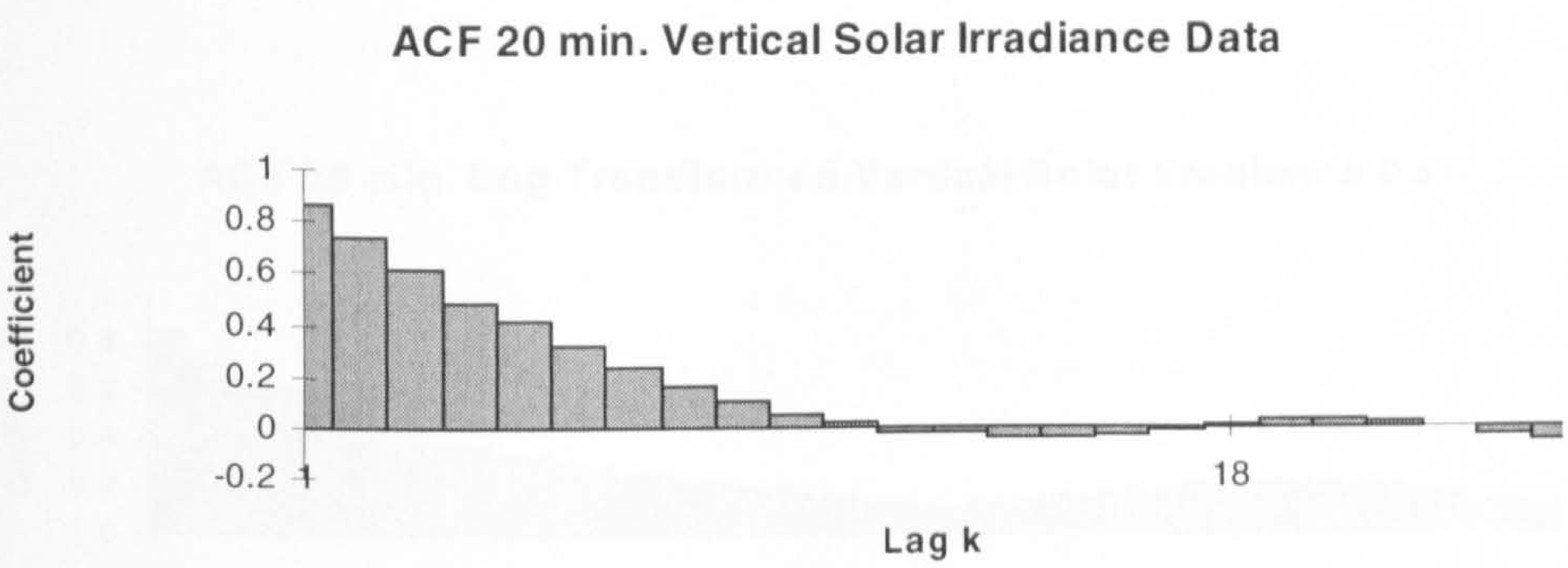


Figure 4.14.3 Vertical Solar Irradiance - 20 minute averages, DEC94_20

a)



b)



c)

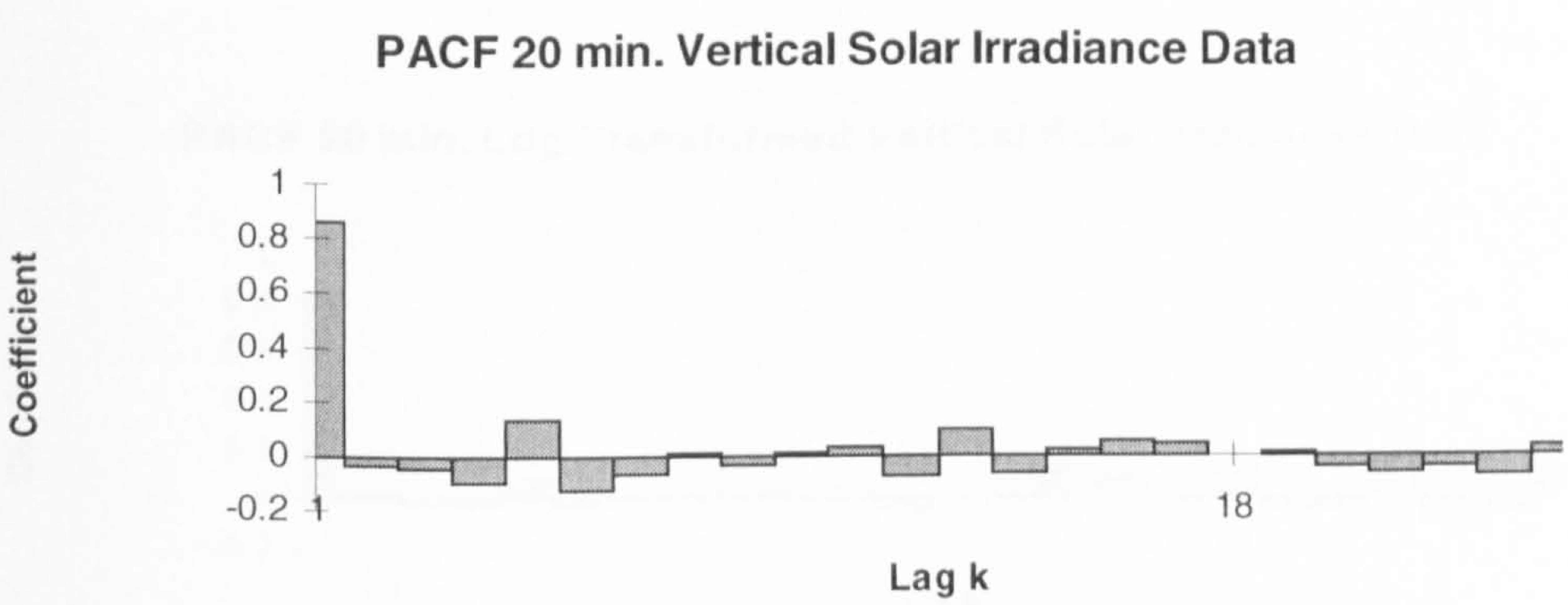
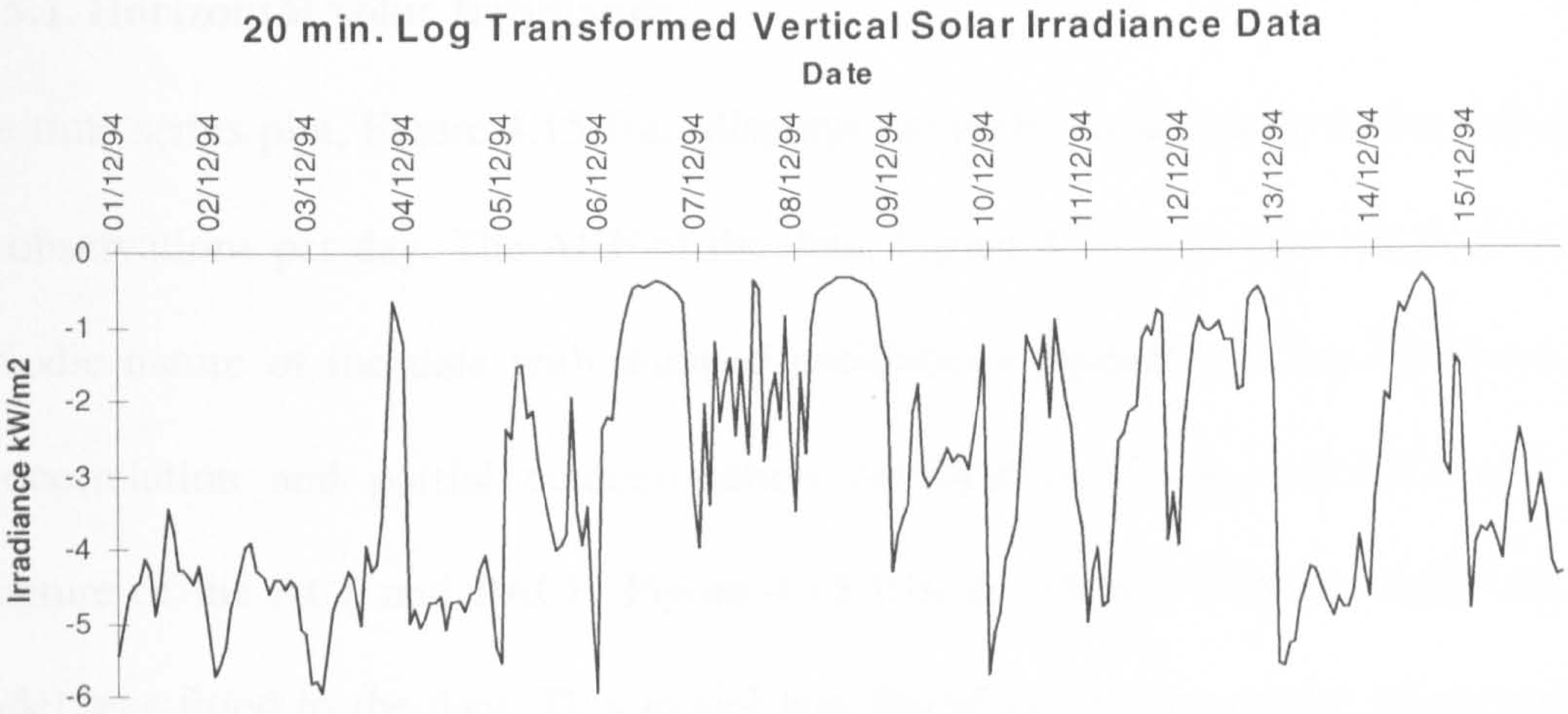
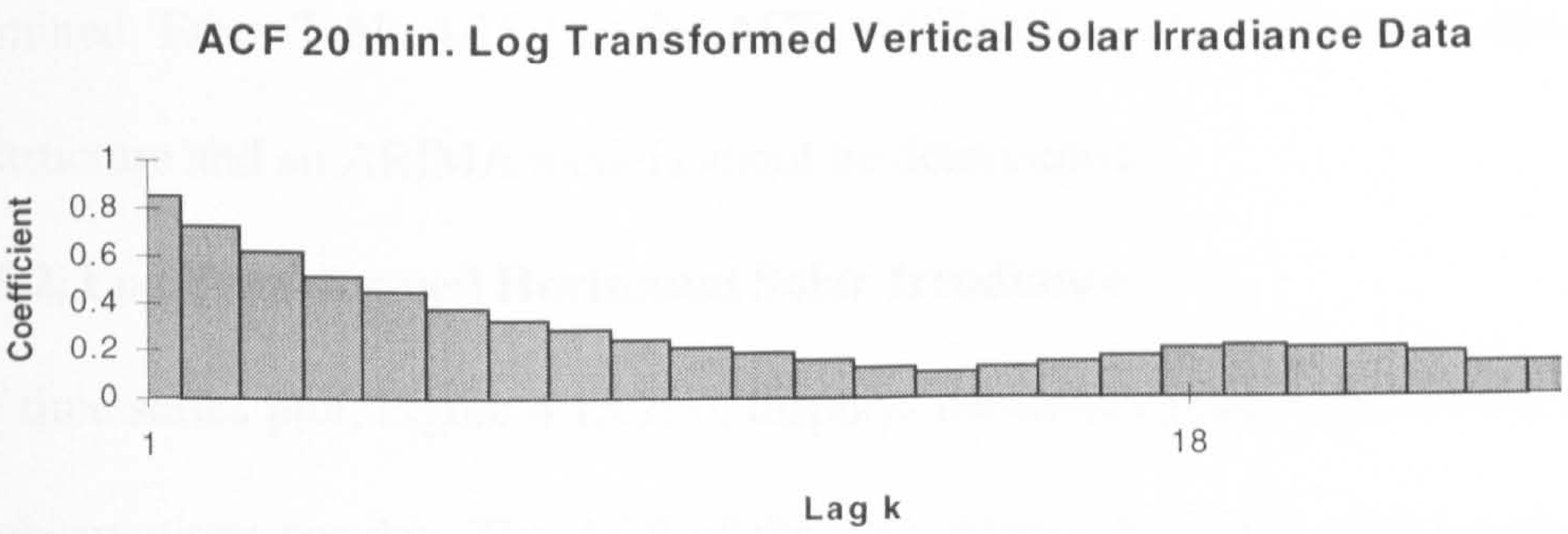


Figure 4.14.4 Log transformed Vertical Solar Irradiance - 20 minute averages, DEC94_20

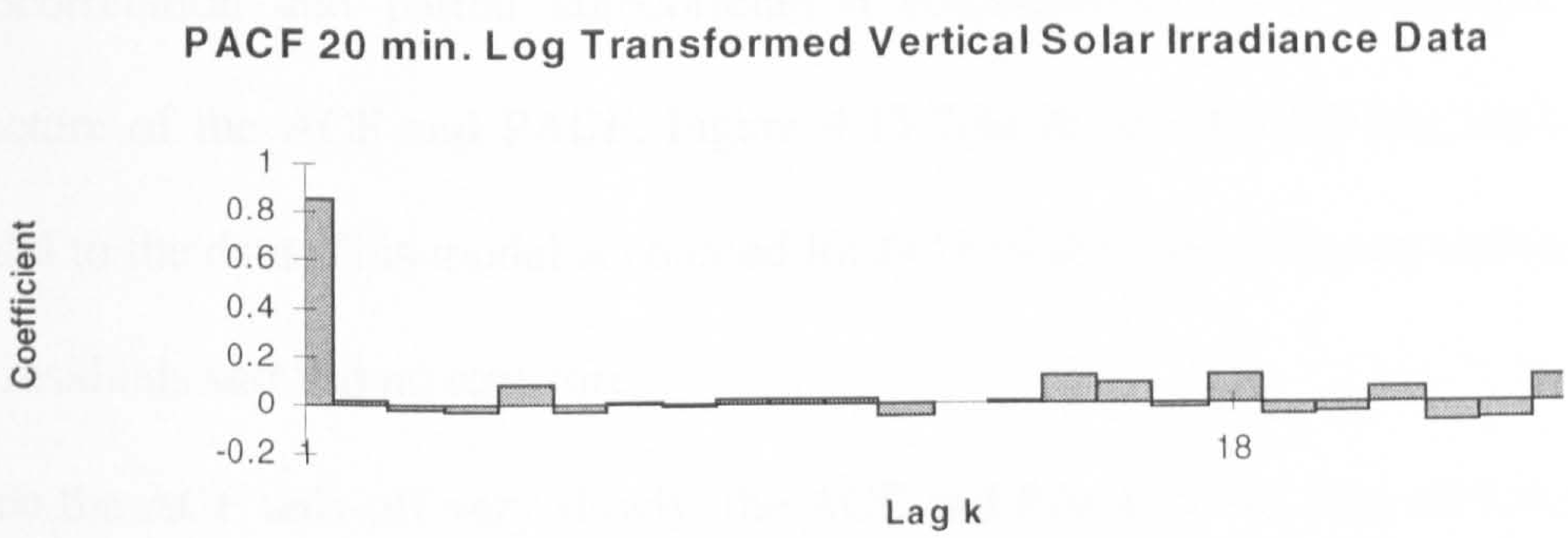
a)



b)



c)



4.15. December 1994 (1st - 15th) - Thirty minute averages

This data set, known as DEC94_10, contains 10 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 1st and 15th December 1994.

4.15.1. Horizontal Solar Irradiance

The time series plot, Figure 4.15.1(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.15.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.15.1(b), and the structure of the ACF and PACF, Figure 4.15.1(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model was found to be appropriate, accounted for 70% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.15.1(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model cannot be determined.

4.15.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.15.2(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.15.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.15.2(b), and the structure of the ACF and PACF, Figure 4.15.2(b) & (c) an ARIMA(1,0,0)(1,0,0)12 model to the data. This model accounted for 66% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.15.2(b) an ARIMA(0,1,0)(1,0,0)12 model was fitted to the

data. This model accounted for 62% of the total variance and the ACF of the residuals showed no structure.

4.15.3. Vertical Solar Irradiance

The time series plot, Figure 4.15.3(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.15.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.15.3(b), and the structure of the ACF and PACF, Figure 4.15.3(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model was found to be appropriate, accounted for 67% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.15.3(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model cannot be determined.

4.15.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.15.4(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.15.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.15.4(b), and the structure of the ACF and PACF, Figure 4.15.4(b) & (c) an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model accounted for 65% of the total variance and the ACF of the residuals showed no structure.

Since the ACF of the data tails-off very slowly first differences were examined. The autocorrelation and partial autocorrelation coefficients of the first differenced data, also summarised in Table 4.15.4(b), suggest fitting an ARIMA(0,1,0)(1,0,0)12 model.

This model accounted for 62% of the total variance and the ACF of the residuals

Table 4.15.1 Summary information for Horizontal Solar Irradiance - 30 minute averages (datafile DEC94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.06306	0.04982	0.0058	0.18083

b)

$2/\sqrt{180} = 0.149$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.821	0.821	0.107	0.107
2	0.606	-0.207	0.036	0.024
3	0.382	-0.153	-0.108	-0.116
4	0.198	-0.031	-0.168	-0.149
12	0.319	-0.018	0.202	0.047

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)12	AR1	0.8182	0.0437	18.72	0.13403	0.00757	70
	SA12	0.2328	0.0748	3.11			
	CONST	0.0083	0.0021	4.05			

Table 4.15.2 Summary information for Log Transformed Horizontal Solar Irradiance - 30 minute averages (datafile DEC94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.1239	0.9047	-5.1499	-1.7102

b)

$2/\sqrt{180} = 0.149$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.776	0.776	0.014	0.014
2	0.557	-0.115	-0.037	-0.037
3	0.360	-0.083	-0.118	-0.118
4	0.218	-0.005	-0.129	-0.129
12	0.377	0.083	0.304	0.162

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)12	AR1	0.7788	0.0477	16.33	49.1187	0.2775	66
	SAR12	0.3572	0.0720	4.96			
	CONST	-0.4546	0.03937	-11.55			
ARIMA(0,1,0)(1,0,0)12	SAR12	0.3423	0.0724	4.73	55.4521	0.3115	62

Table 4.15.3 Summary information for Vertical Solar Irradiance - 30 minute averages (datafile DEC94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1566	0.2078	0.0026	0.7125

b)

$2/\sqrt{180} = 0.149$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.817	0.817	0.013	0.013
2	0.630	-0.114	-0.055	-0.055
3	0.463	-0.053	-0.094	-0.093
4	0.331	-0.012	-0.029	-0.031
12	0.018	0.042	0.052	-0.019

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)12	AR1	0.8225	0.0431	19.10	2.52549	0.01427	67
	SAR12	0.0514	0.0753	0.68			
	CONST	0.02498	0.00891	2.80			

Table 4.15.4 Summary information for Log Transformed Vertical Solar Irradiance - 30 minute averages (datafile DEC94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.970	1.638	-5.952	-0.339

b)

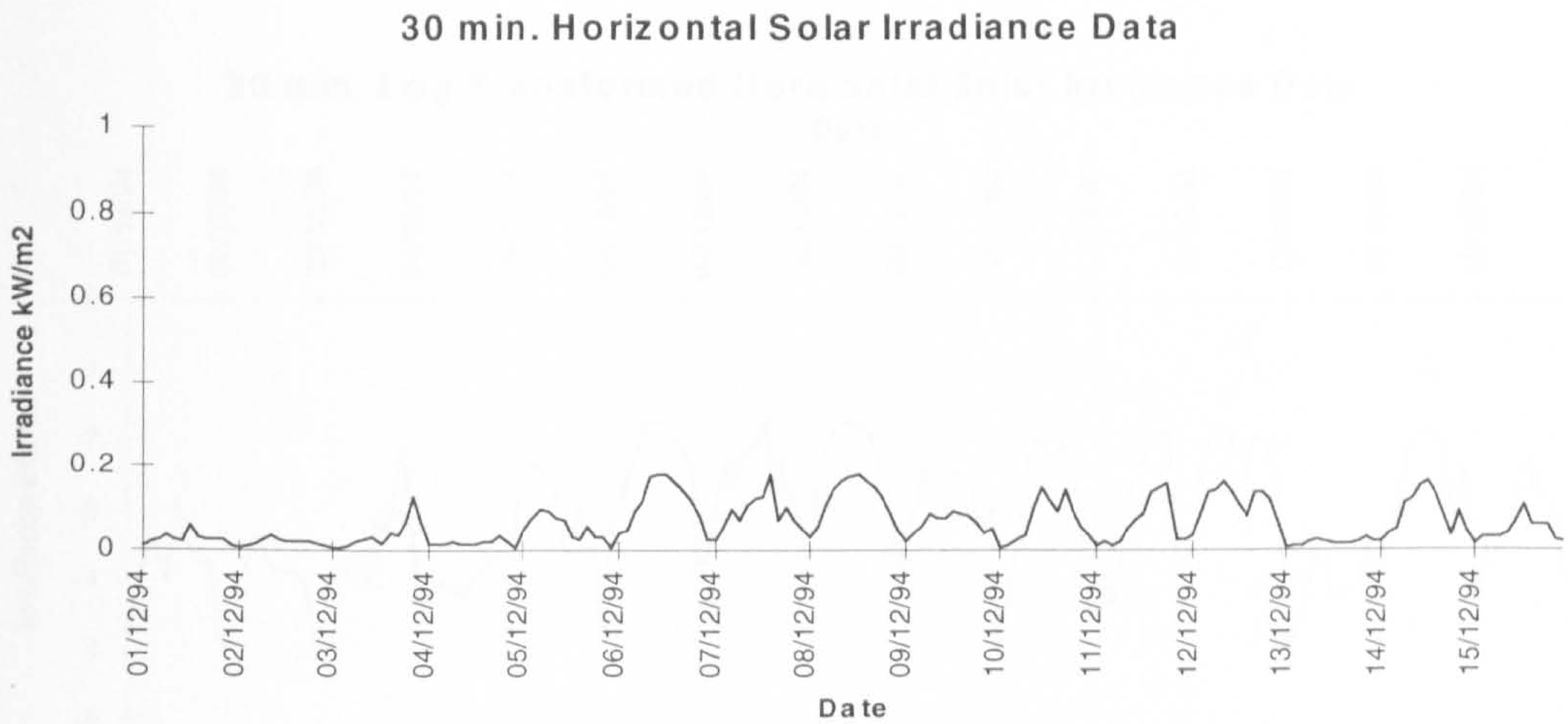
$2/\sqrt{180} = 0.149$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.799	0.799	-0.062	-0.062
2	0.627	-0.034	-0.079	-0.083
3	0.488	-0.008	-0.117	-0.129
4	0.396	-0.045	-0.038	-0.064
12	0.214	0.079	0.122	0.019

c)

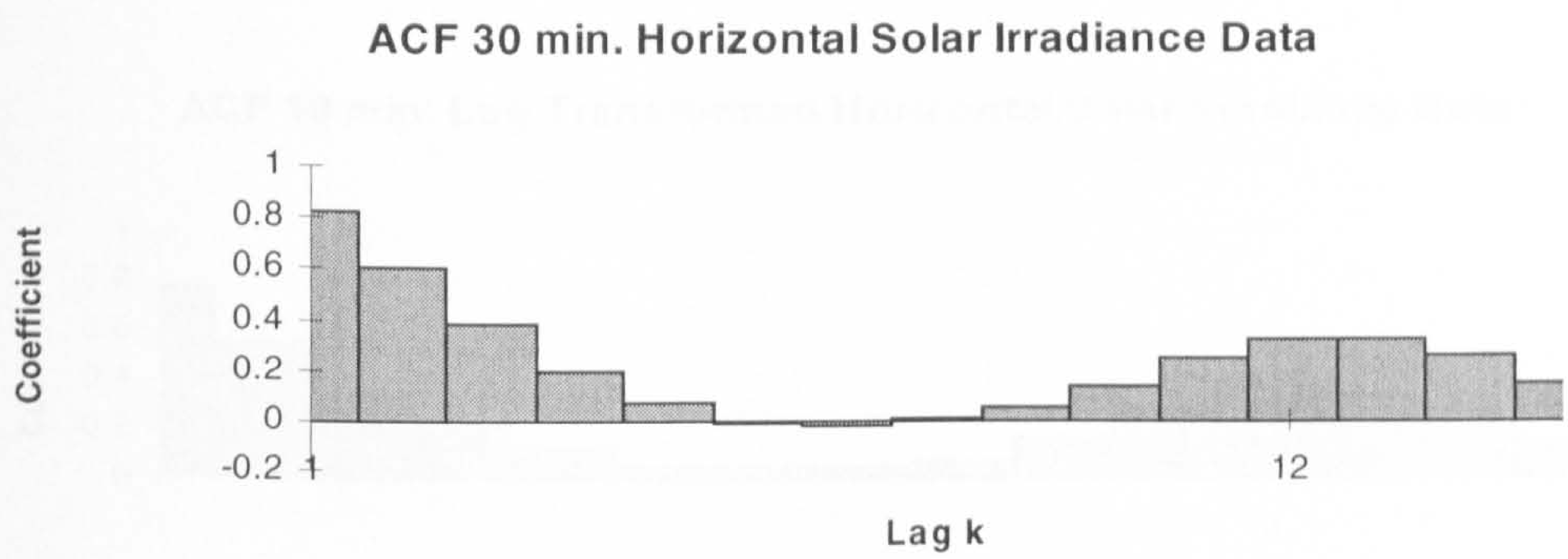
model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)12	AR1	0.8061	0.0450	17.91	163.879	0.926	65
	SAR12	0.1450	0.0754	1.92			
	CONST	-0.5109	0.07187	-7.11			
ARIMA(0,1,0)(1,0,0)12	SAR12	0.1284	0.0756	1.70	182.058	1.023	62

Figure 4.15.1 Horizontal Solar Irradiance - 30 minute averages, DEC94_30

a)



b)



c)

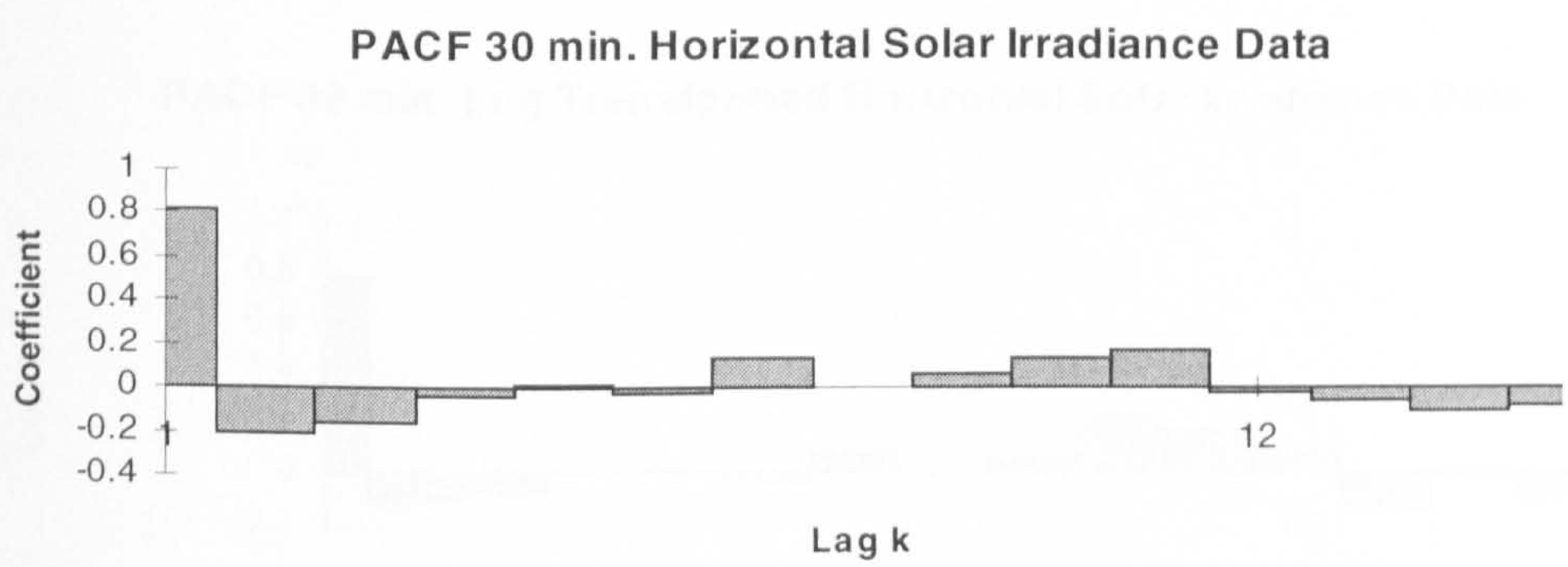
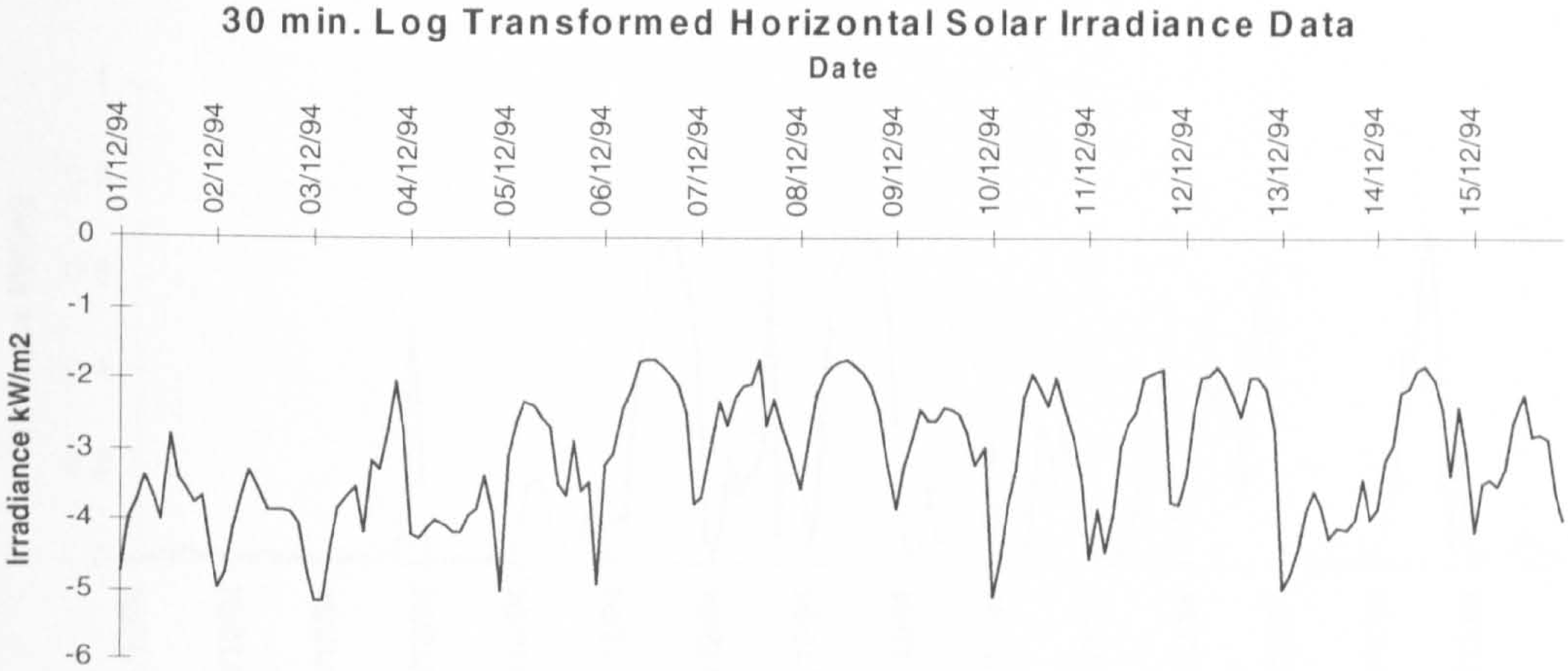
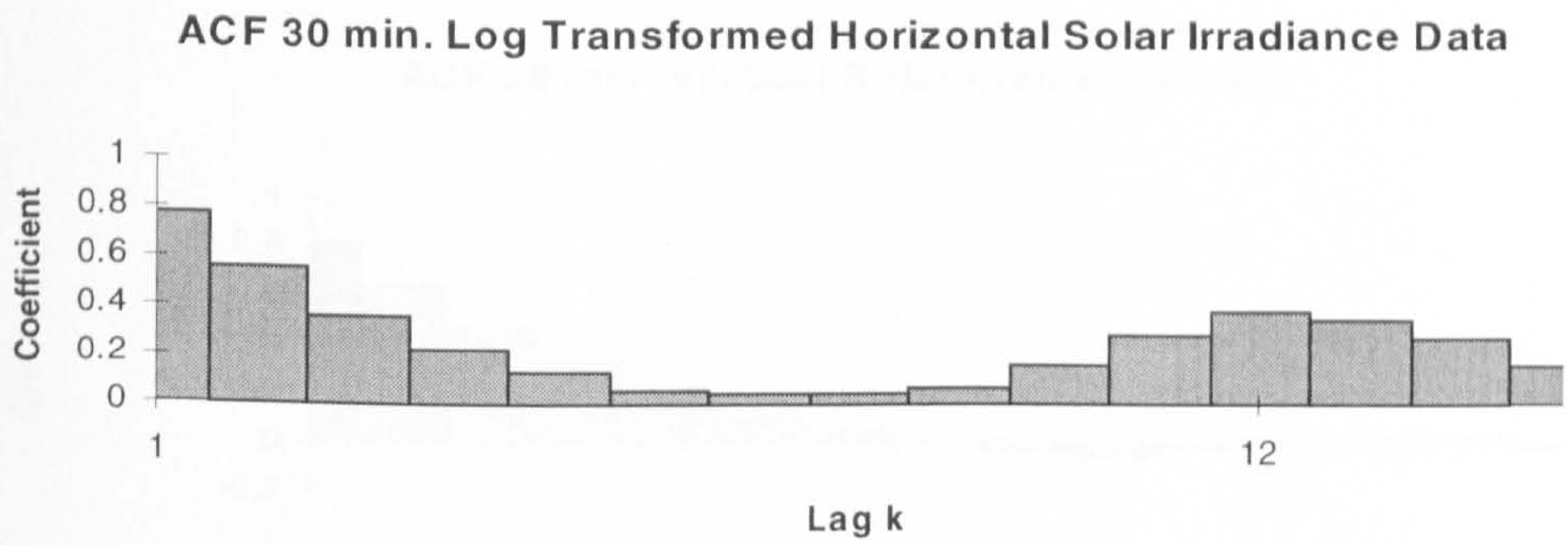


Figure 4.15.2 Log transformed Horizontal Solar Irradiance - 30 minute averages, DEC94_30

a)



b)



c)

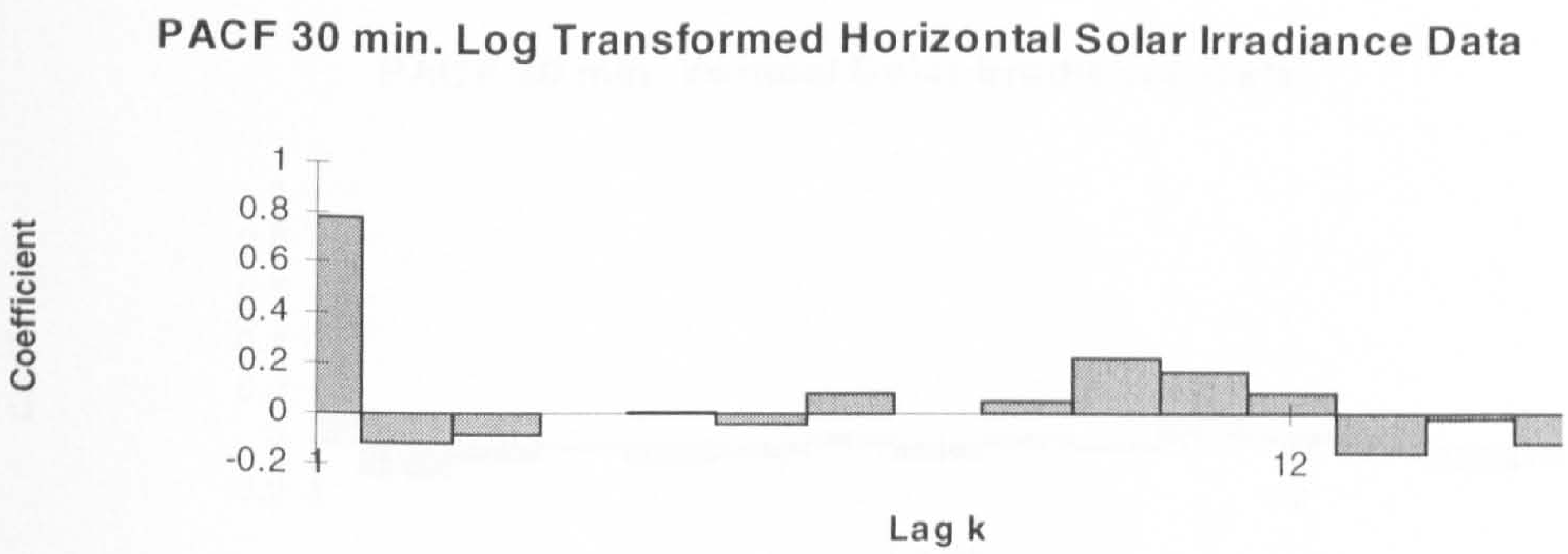
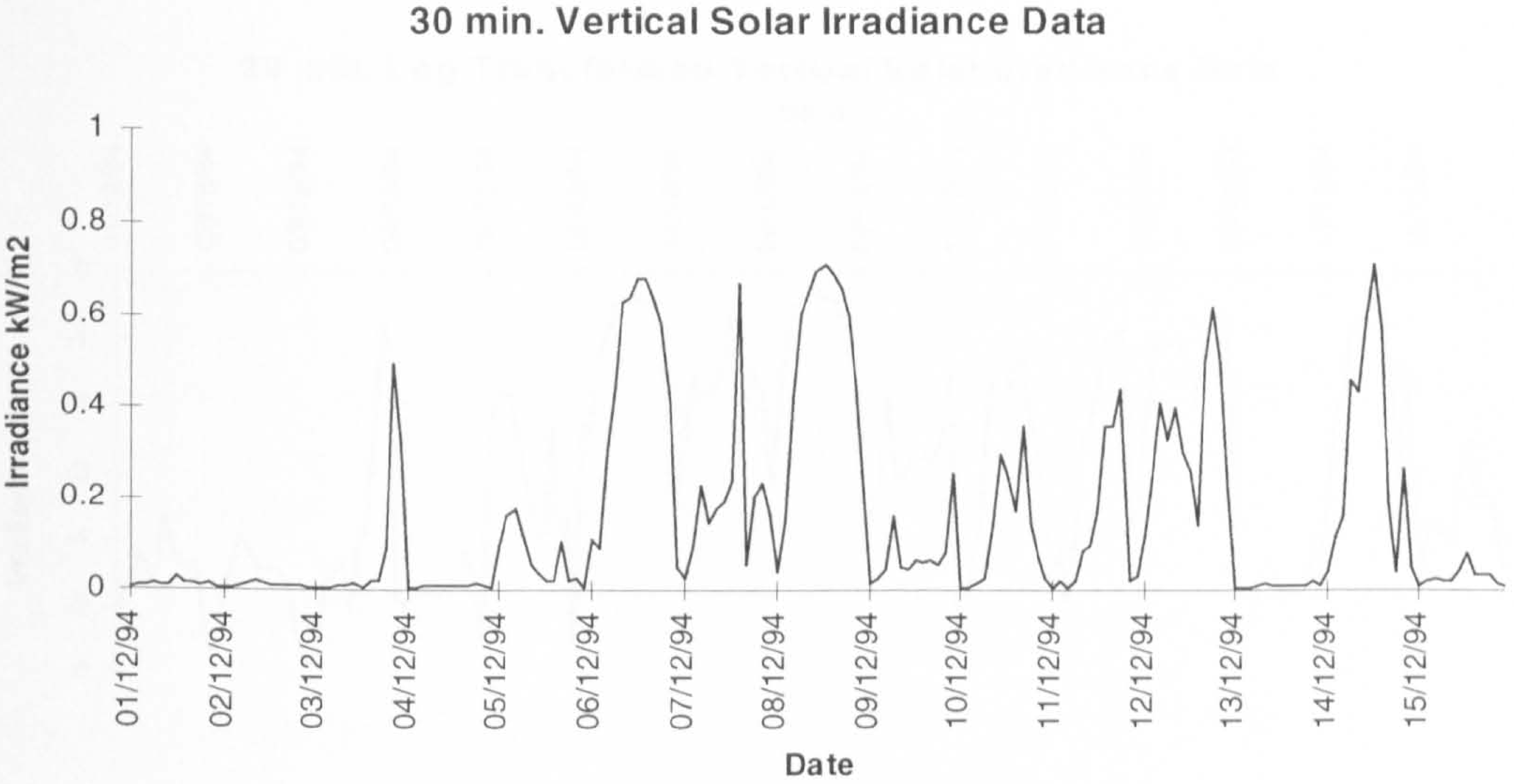
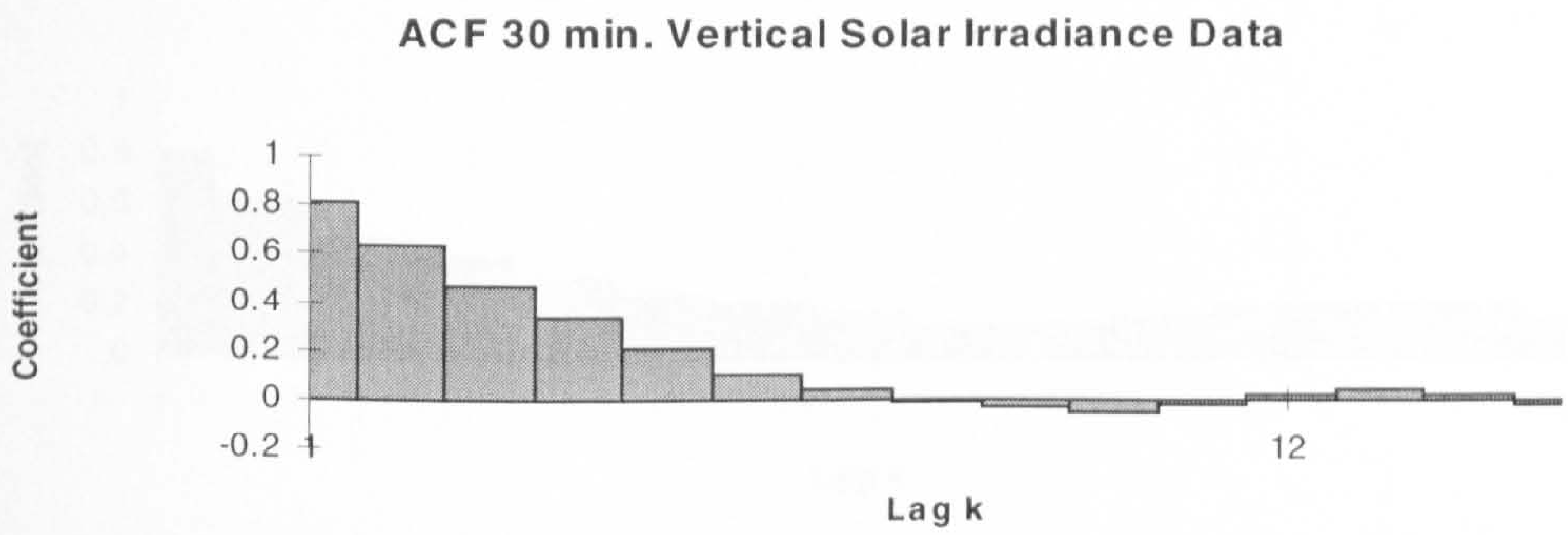


Figure 4.15.3 Vertical Solar Irradiance - 30 minute averages, DEC94_30

a)



b)



c)

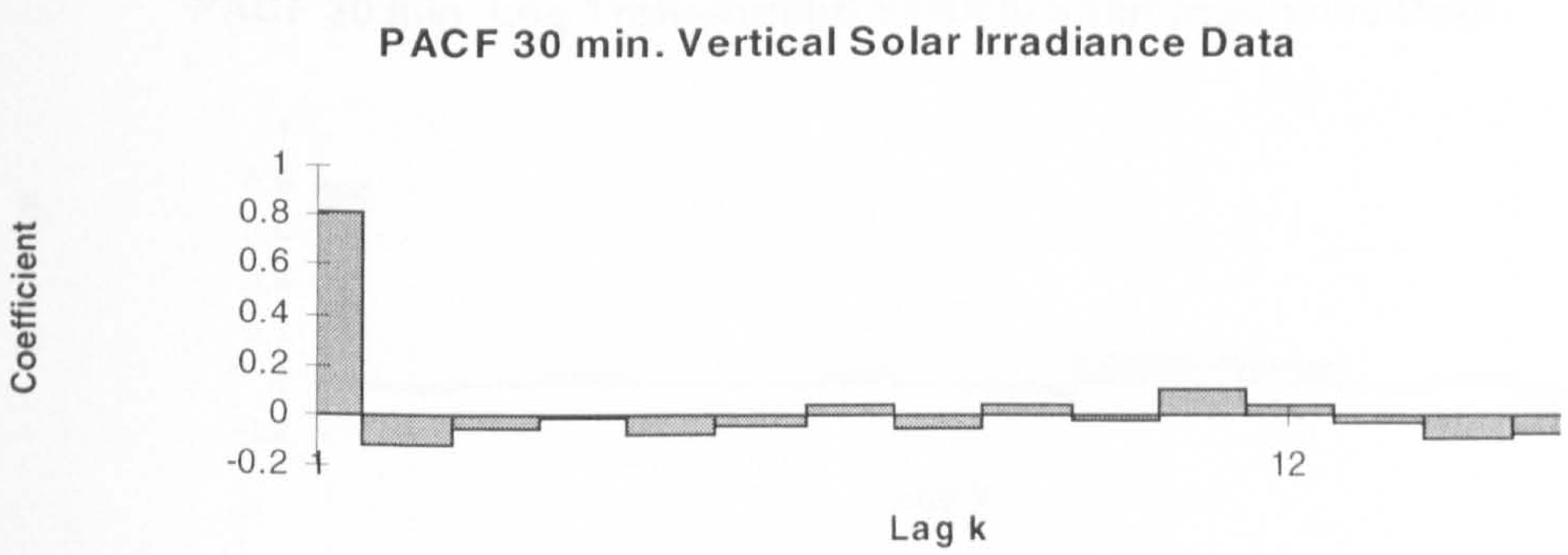
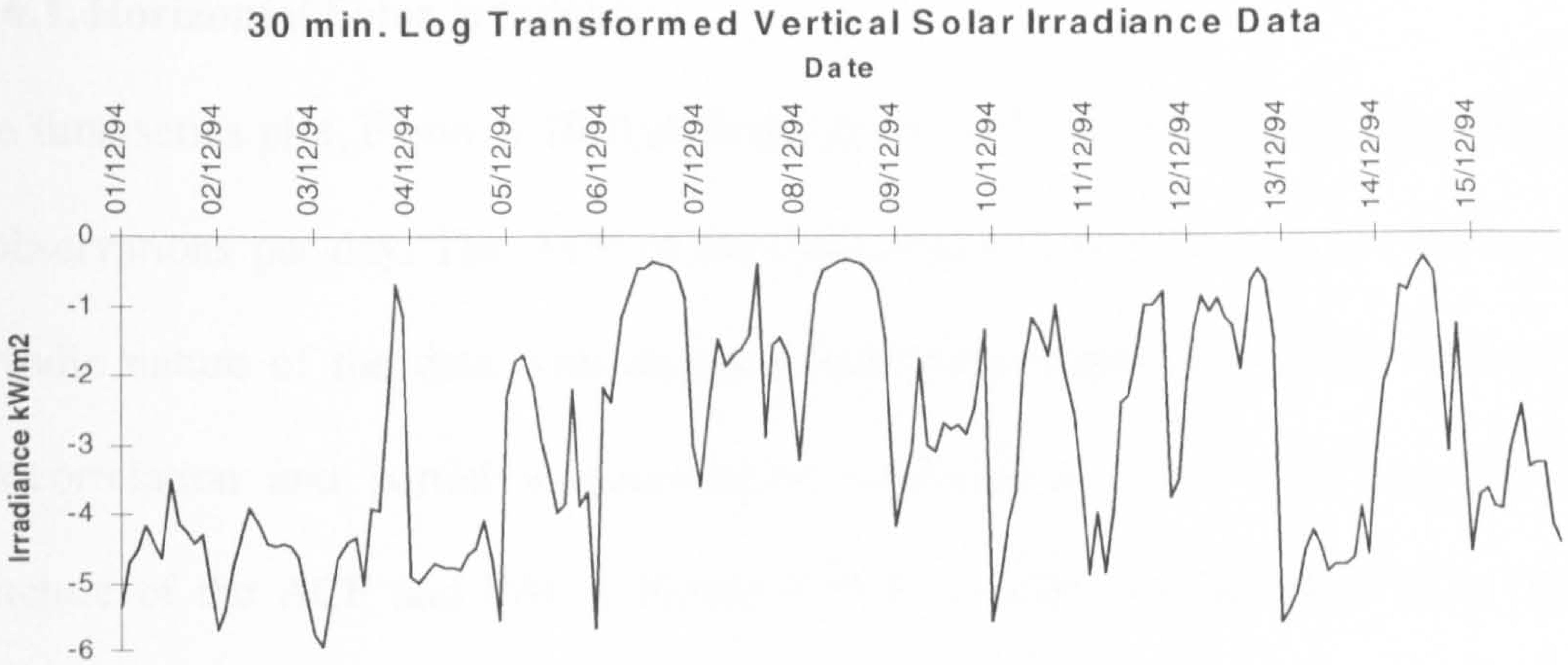
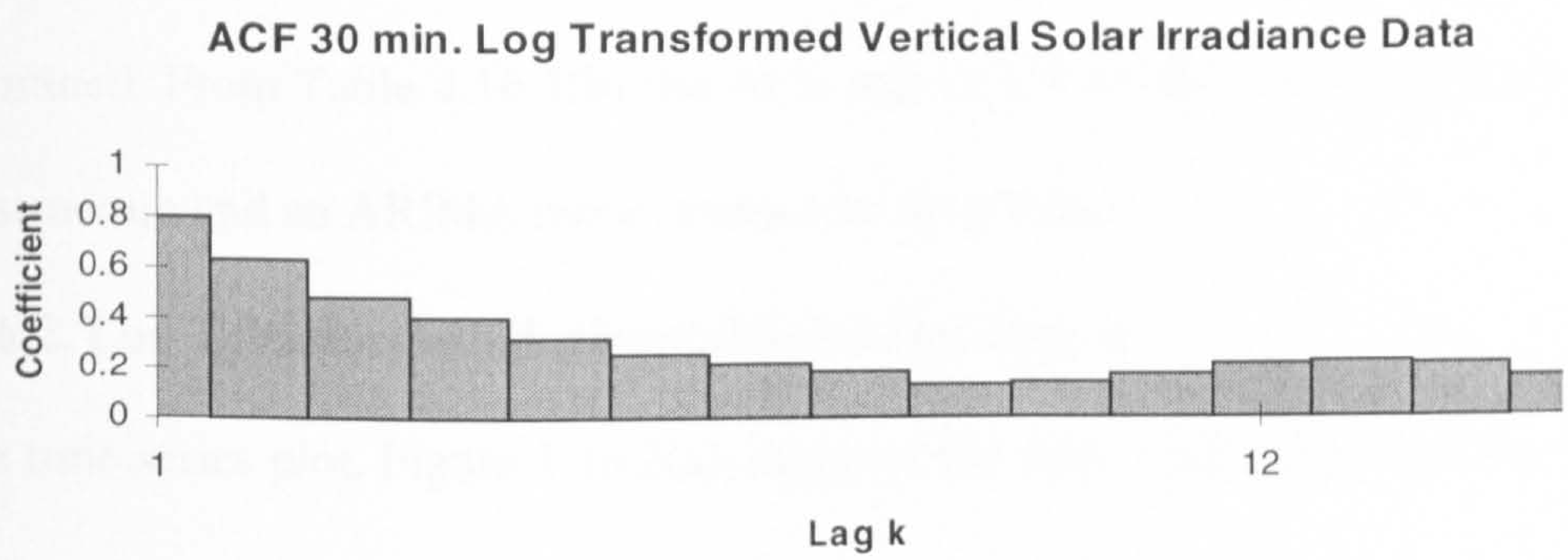


Figure 4.15.4 Log transformed Vertical Solar Irradiance - 30 minute averages, DEC94_30

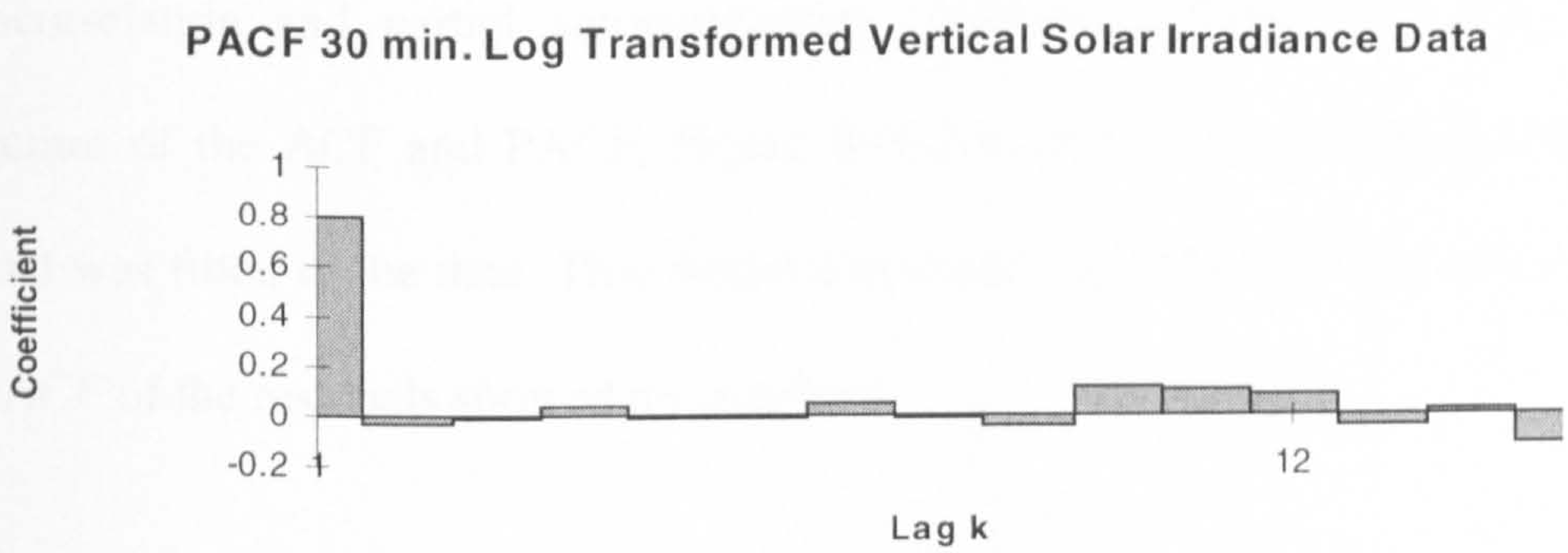
a)



b)



c)



4.16. December 1994 (1st - 15th) - Sixty minute averages

This data set, known as DEC94_60, contains 60 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 1st and 15th December 1994.

4.16.1. Horizontal Solar Irradiance

The time series plot, Figure 4.16.1(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.16.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.16.1(b), and the structure of the ACF and PACF, Figure 4.16.1(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model was found to be appropriate, accounted for 47% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.16.1(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model cannot be determined.

4.16.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.16.2(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.16.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.16.2(b), and the structure of the ACF and PACF, Figure 4.16.2(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 43% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.16.2(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model cannot be determined.

4.16.3. Vertical Solar Irradiance

The time series plot, Figure 4.16.3(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.16.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.16.3(b), and the structure of the ACF and PACF, Figure 4.16.3(b) &(c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model was found to be appropriate, accounted for 44% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.16.3(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model cannot be determined.

4.16.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.16.4(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.16.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.16.4(b), and the structure of the ACF and PACF, Figure 4.16.4(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 44% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.16.4(b) the ACF and PACF of the differenced series shows no structure and an ARIMA model cannot be determined.

Table 4.16.1 Summary information for Horizontal Solar Irradiance - 60 minute averages (datafile DEC94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.06306	0.04831	0.00587	0.17727

b)

$2/\sqrt{90} = 0.211$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.636	0.636	0.089	0.089
2	0.220	-0.311	-0.270	-0.280
3	-0.002	0.023	-0.339	-0.310
4	0.016	0.142	-0.180	-0.254
6	0.331	0.230	0.337	0.110

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.6486	0.0828	7.83	0.10655	0.001225	47
	SA6	0.3575	0.1025	3.49			
	CONST	0.01337	0.0037	3.62			

Table 4.16.2 Summary information for Log Transformed Horizontal Solar Irradiance - 60 minute averages (datafile DEC94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0948	0.8643	-5.1385	-1.7301

b)

$2/\sqrt{90} = 0.211$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.605	0.605	-0.034	-0.034
2	0.258	-0.170	-0.232	-0.234
3	0.087	0.012	-0.203	-0.233
4	0.079	0.092	-0.152	-0.264
6	0.348	0.267	0.294	0.062

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)6	AR1	0.6058	0.0863	7.02	36.6339	0.4211	43
	SAR6	0.3447	0.1034	3.33			
	CONST	-0.8137	0.06855	-11.87			

Table 4.16.3 Summary information for Vertical Solar Irradiance - 60 minute averages (datafile DEC94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1566	0.2013	0.0029	0.7030

b)

$2/\sqrt{90} = 0.211$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.665	0.665	-0.045	-0.045
2	0.360	-0.146	-0.085	-0.087
3	0.112	-0.119	-0.211	-0.221
4	0.003	0.034	-0.106	-0.147
6	0.023	0.108	0.093	-0.027

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.6763	0.0796	8.49	1.9751	0.0227	44
	SAR6	0.0843	0.1078	0.78			
	CONST	0.0494	0.0159	2.76			
ARIMA(1,0,0)	AR1	0.6727	0.0793	8.49	1.98908	0.0226	44
	CONST	0.04916	0.01586	3.10			

Table 4.16.4 Summary information for Log Transformed Vertical Solar Irradiance - 60 minute averages (datafile DEC94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.908	1.607	-5.849	-0.352

b)

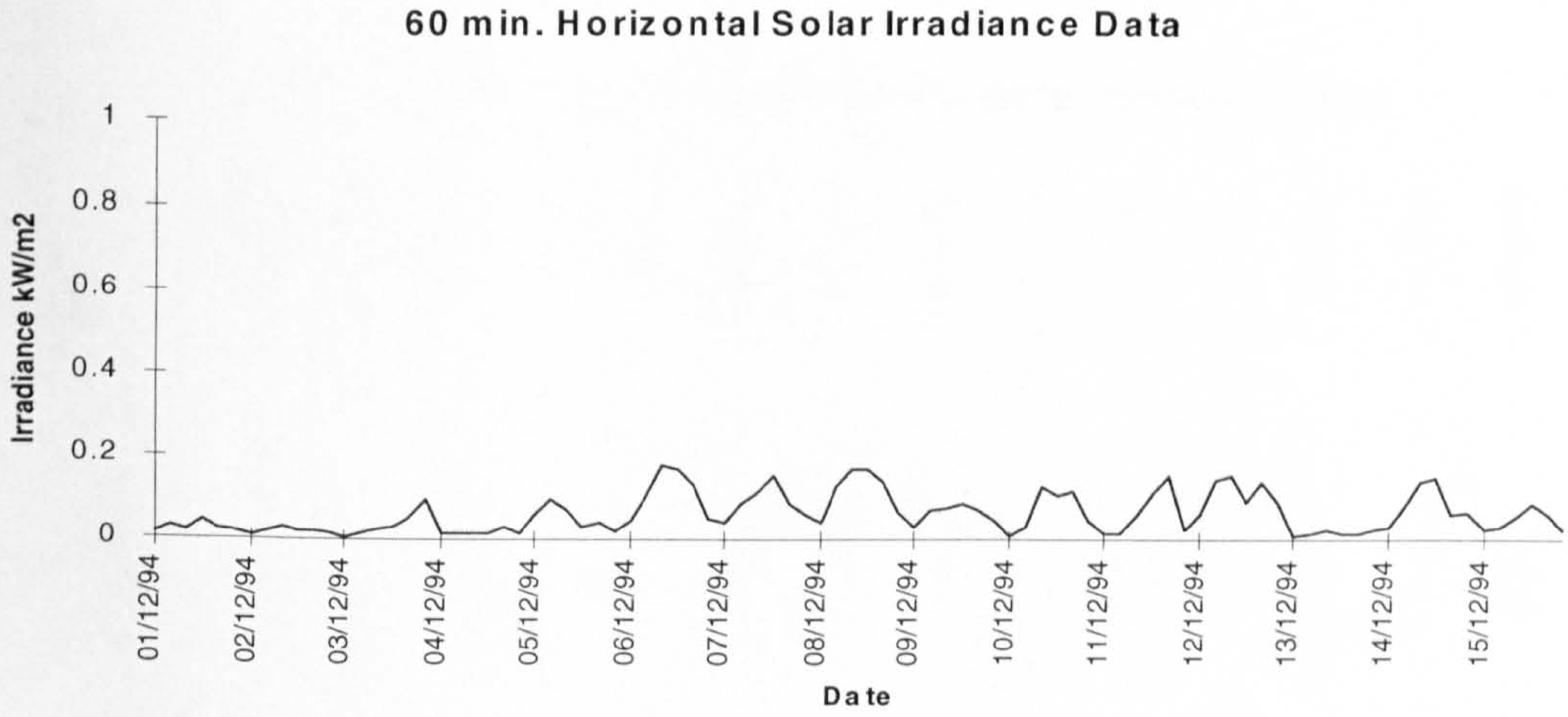
$2/\sqrt{90} = 0.211$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.659	0.659	-0.156	-0.156
2	0.432	-0.004	-0.123	-0.151
3	0.287	0.006	-0.110	-0.163
4	0.217	0.046	-0.019	-0.096
6	0.201	0.169	0.057	-0.092

c)

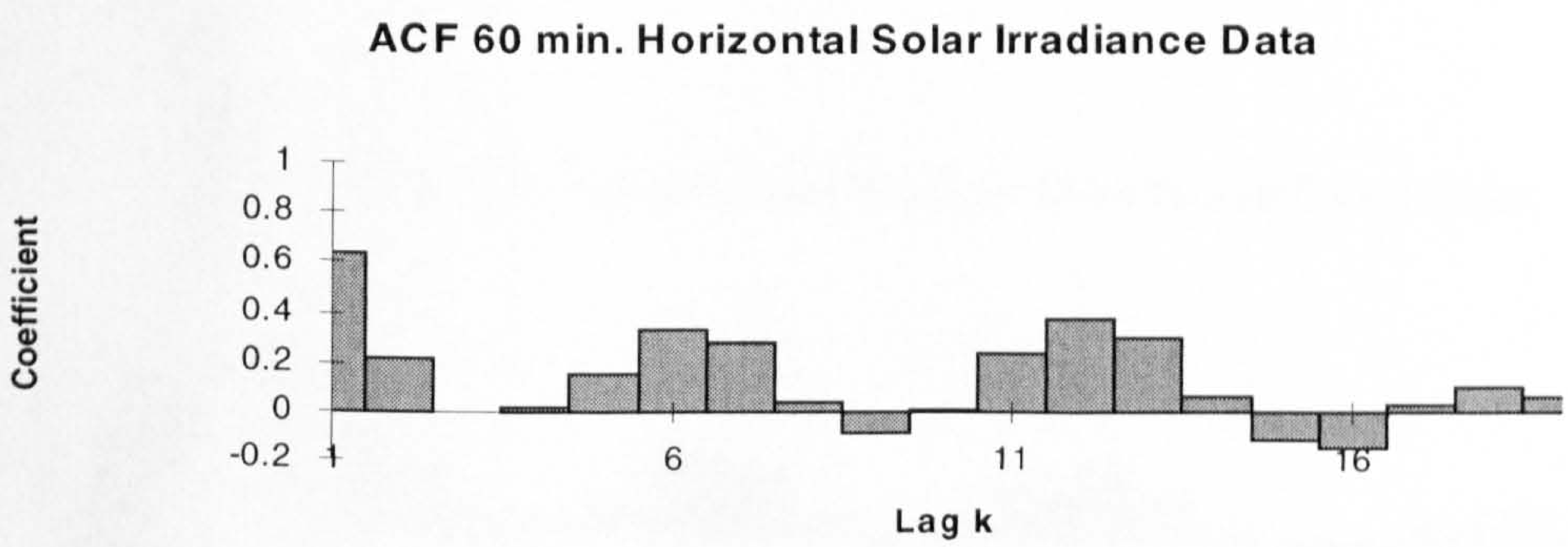
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.6676	0.0806	8.28	125.005	1.437	44
	SAR6	0.0987	0.1086	0.91			
	CONST	-0.8993	01266	-7.10			
ARIMA(1,0,0)	AR1	0.6780	0.0790	8.59	126.098	1.433	44
	CONST	-0.9615	0.1263	-7.61			

Figure 4.16.1 Horizontal Solar Irradiance - 60 minute averages, DEC94_60

a)



b)



c)

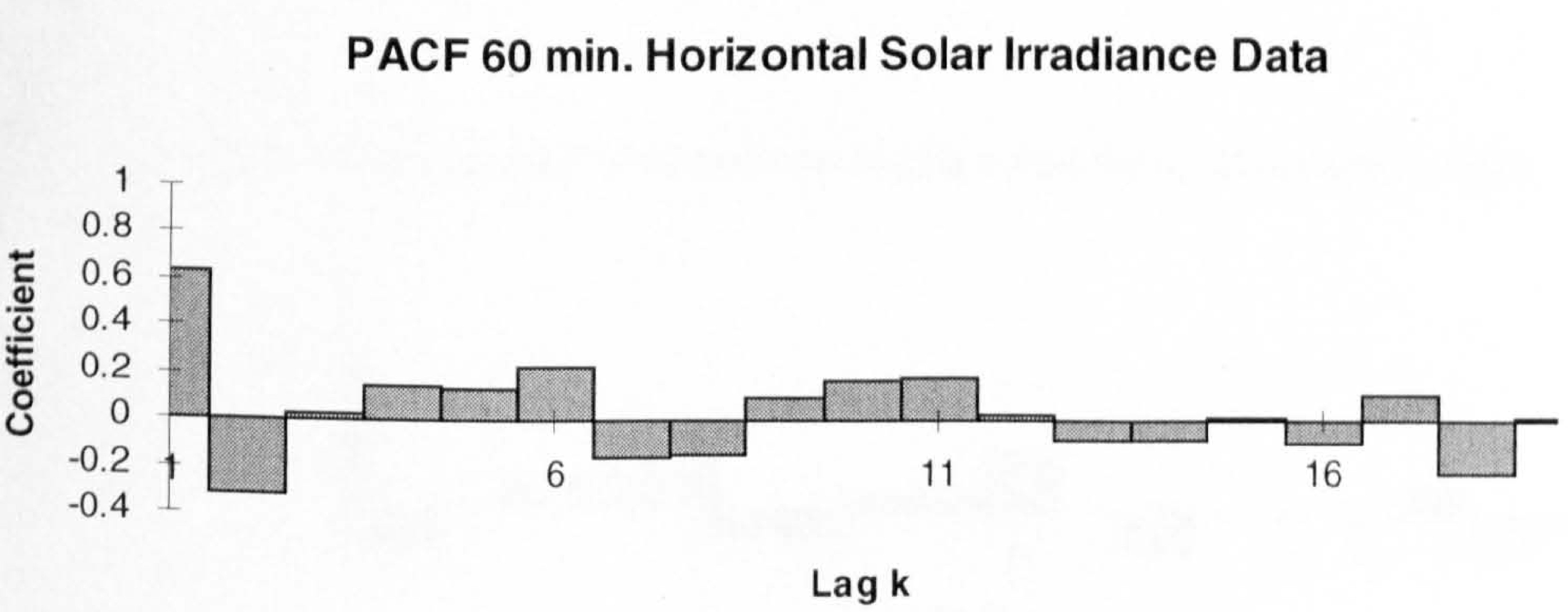
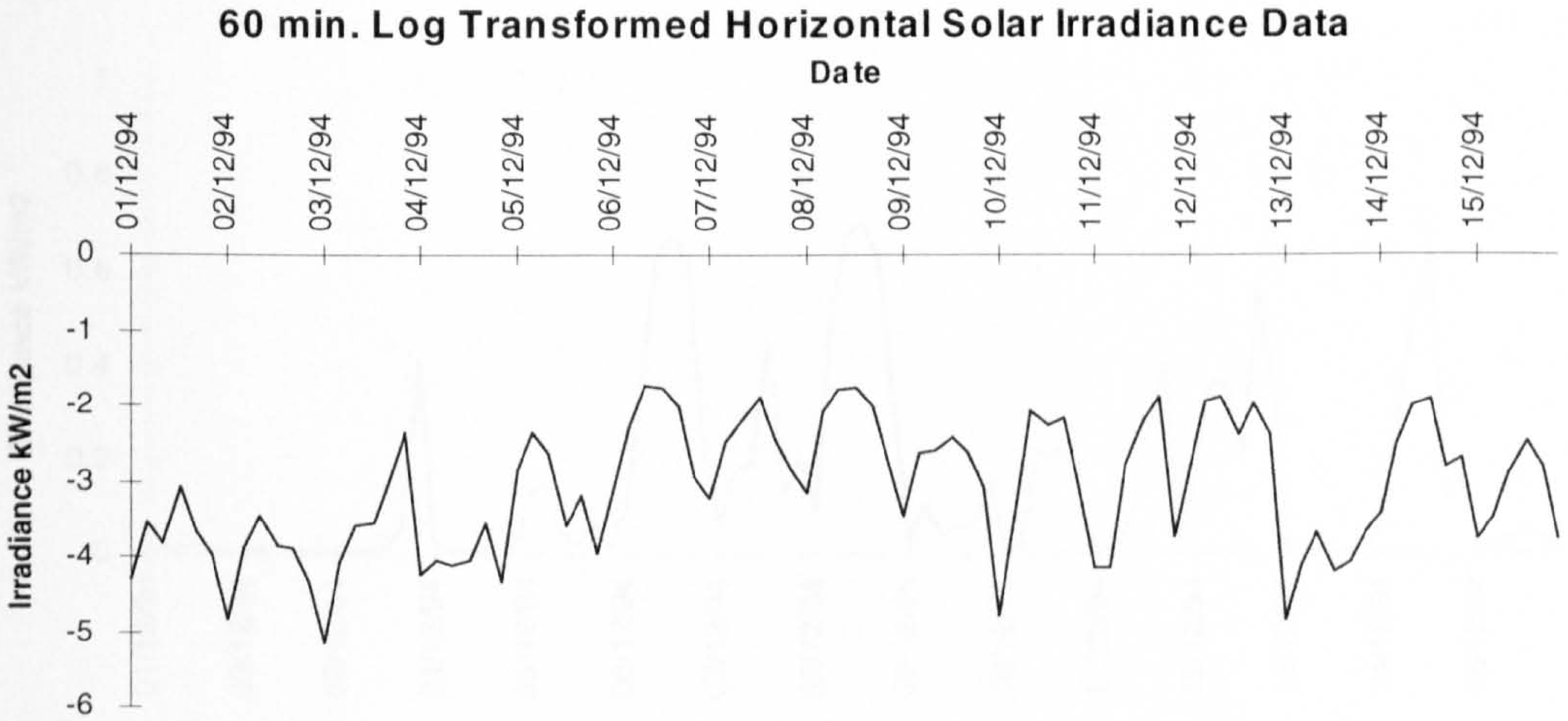
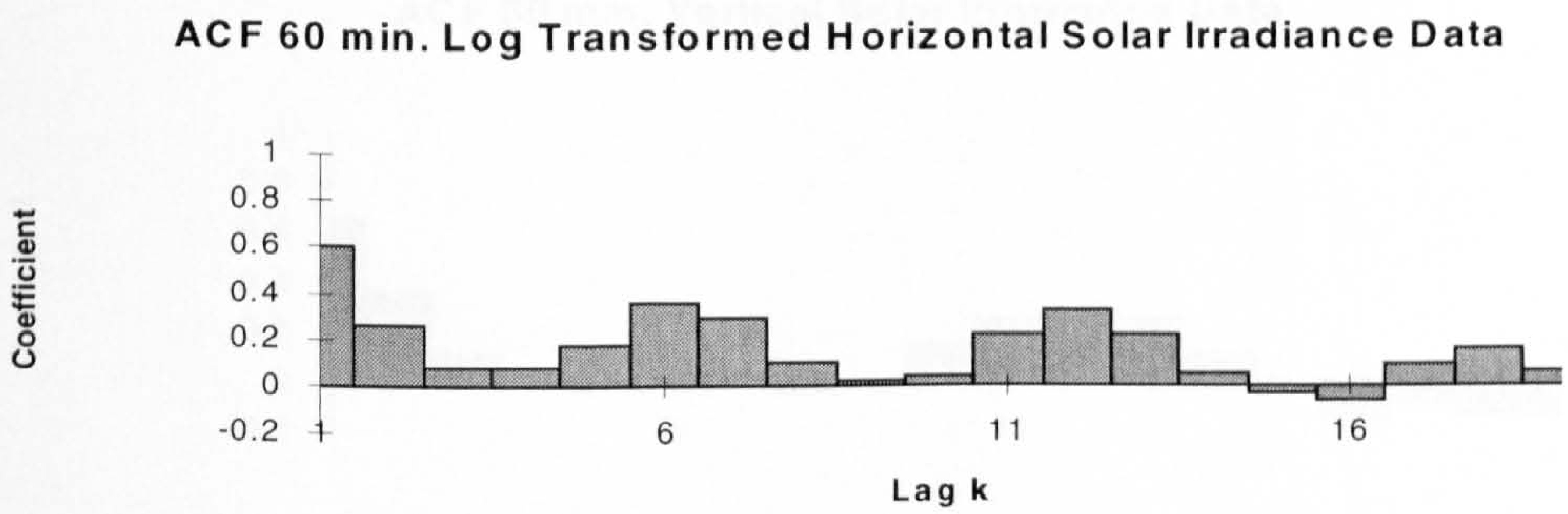


Figure 4.16.2 Log transformed Horizontal Solar Irradiance - 60 minute averages, DEC94_60

a)



b)



c)

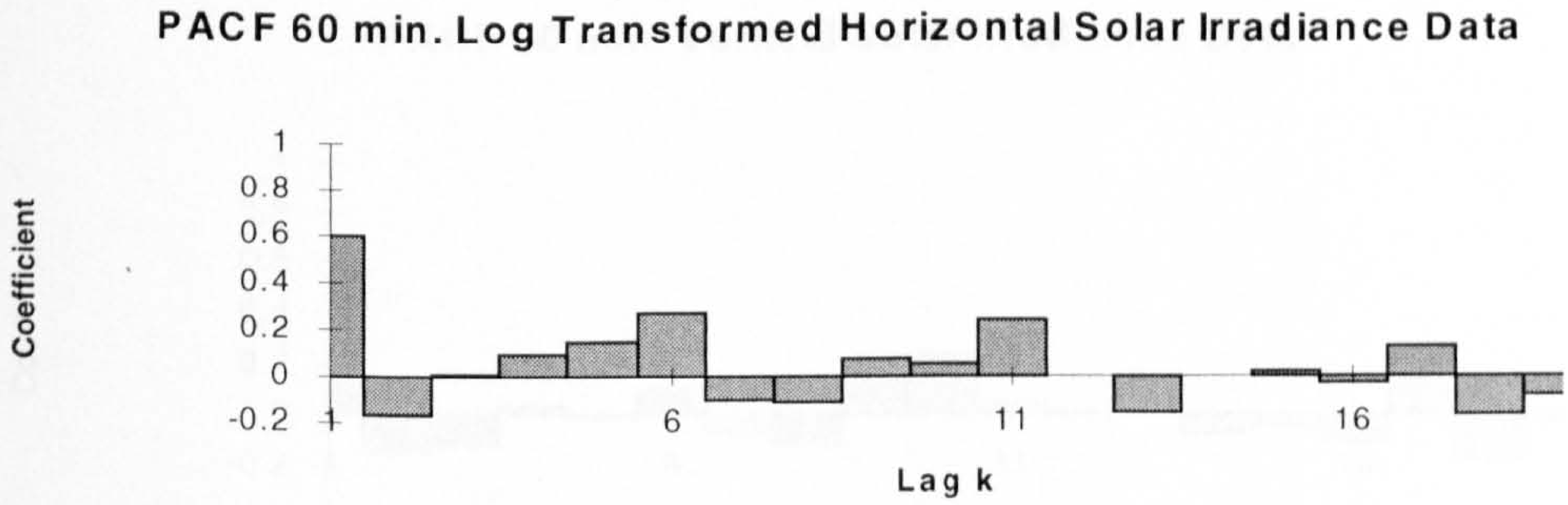
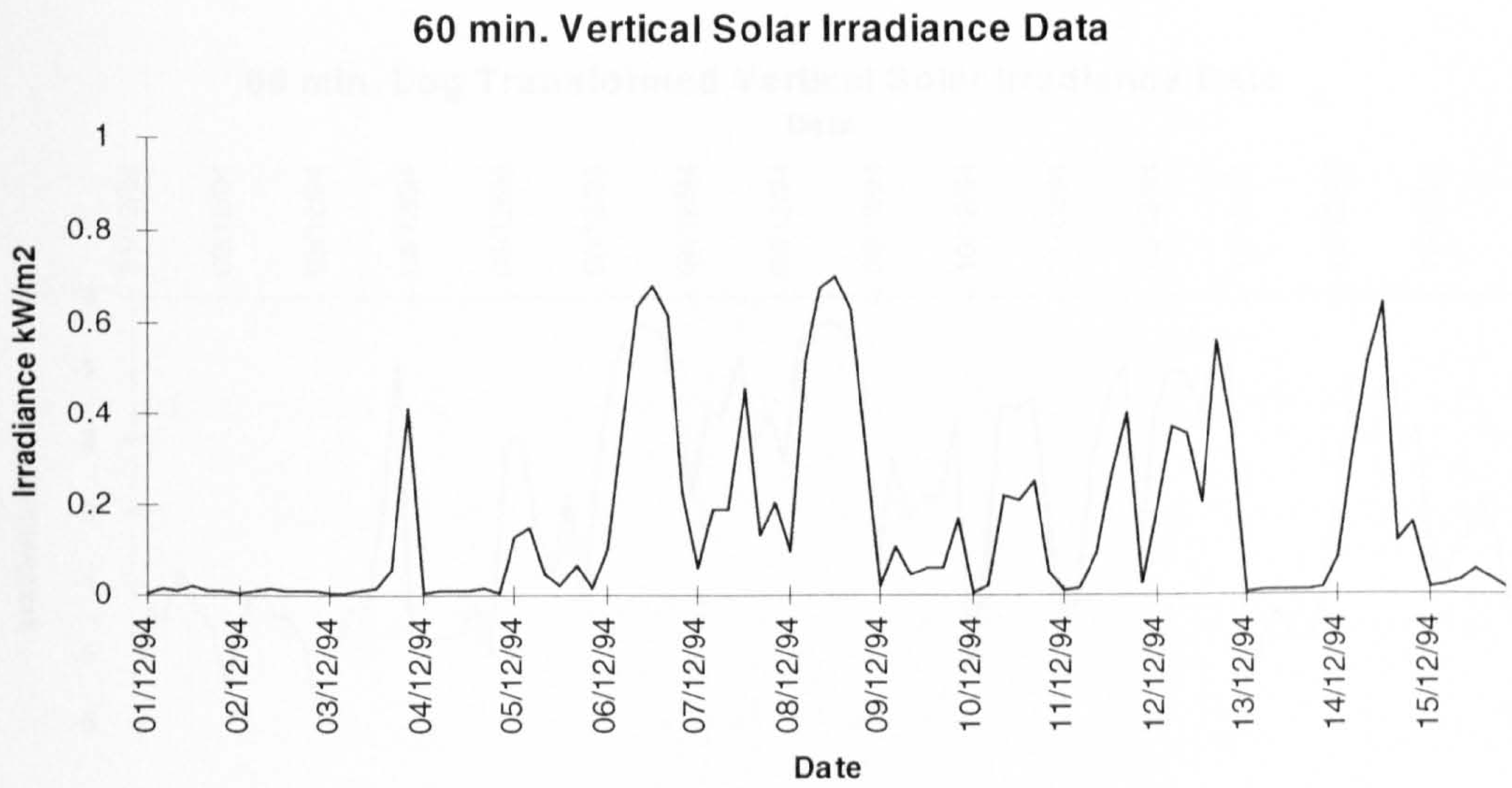
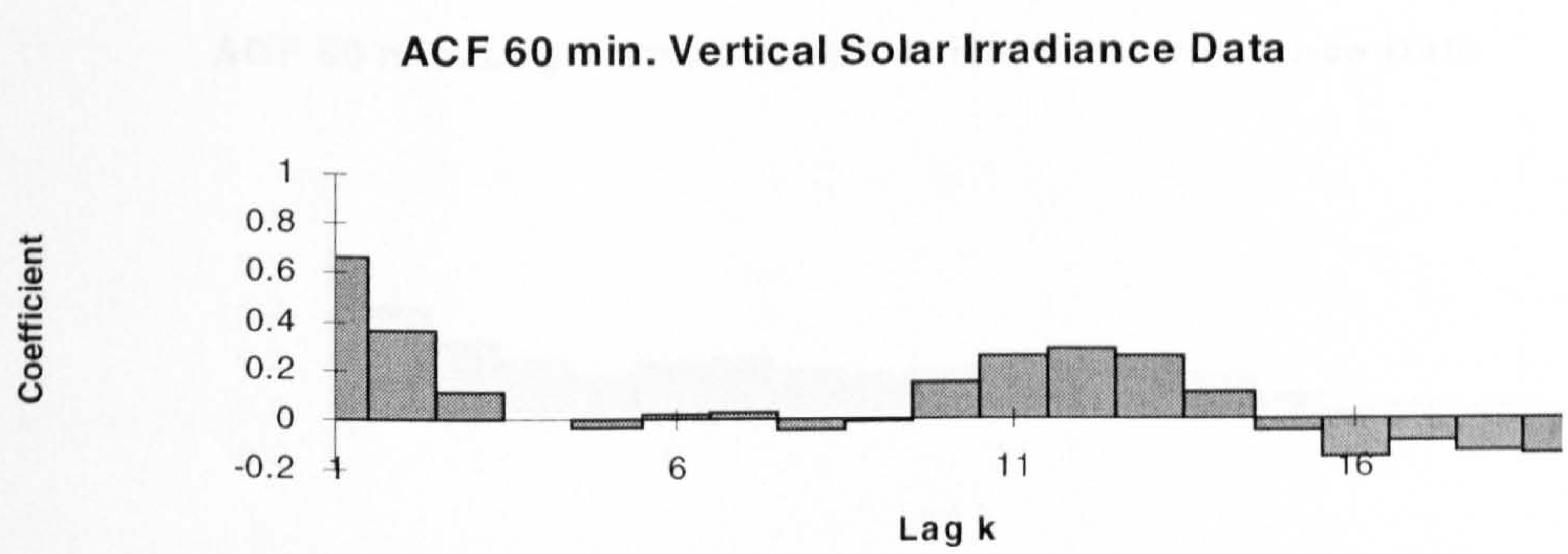


Figure 4.16.3 Vertical Solar Irradiance - 60 minute averages, DEC94_60

a)



b)



c)

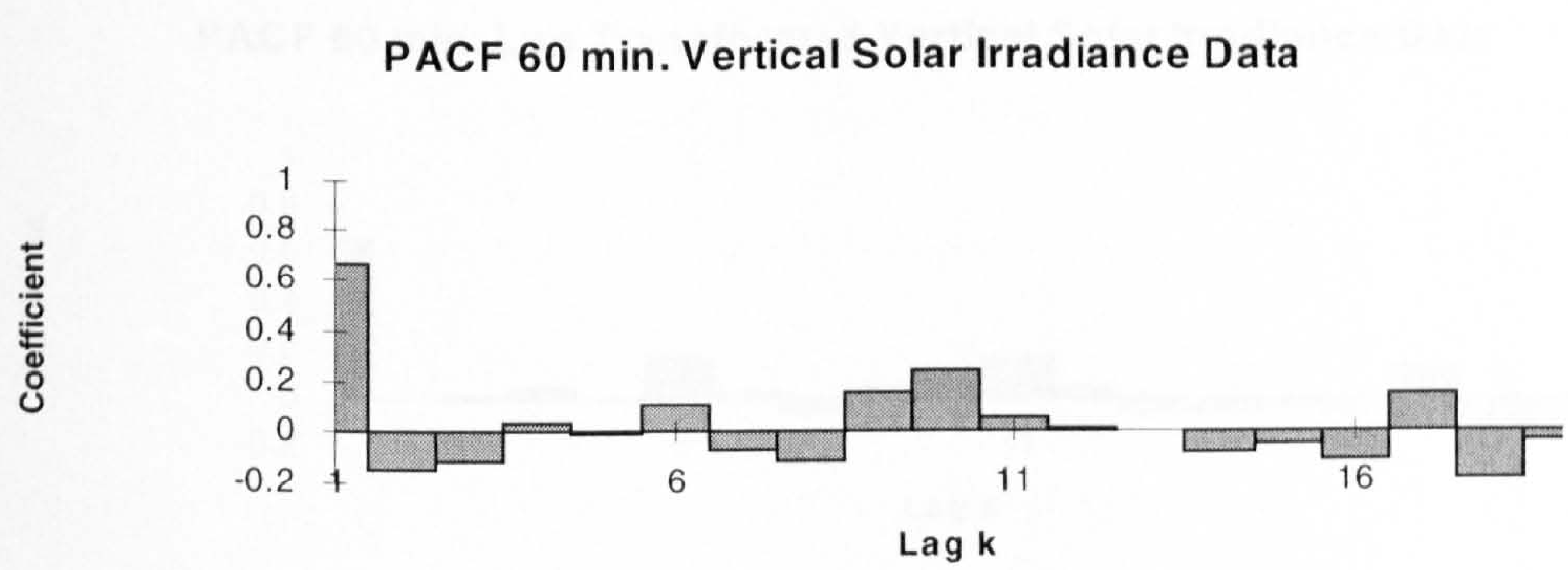
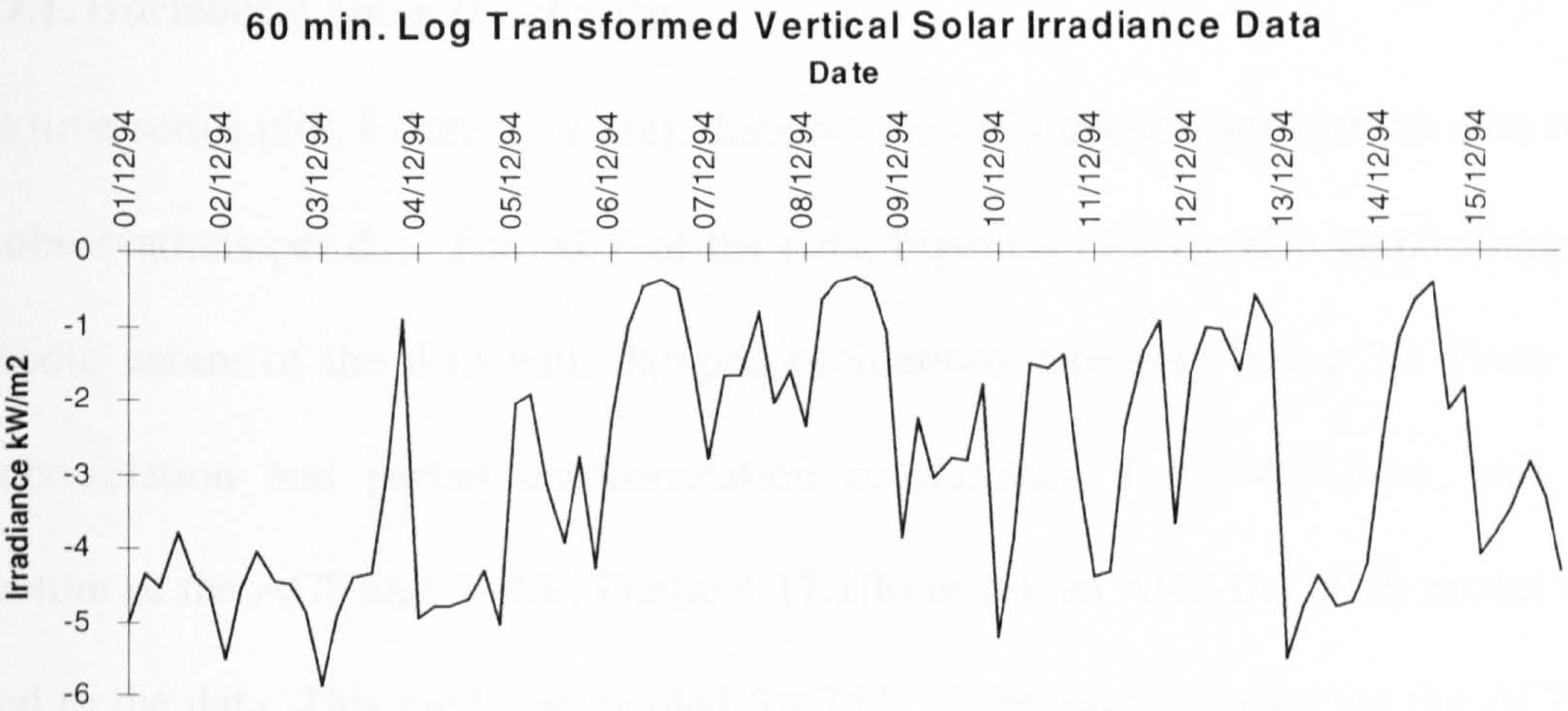
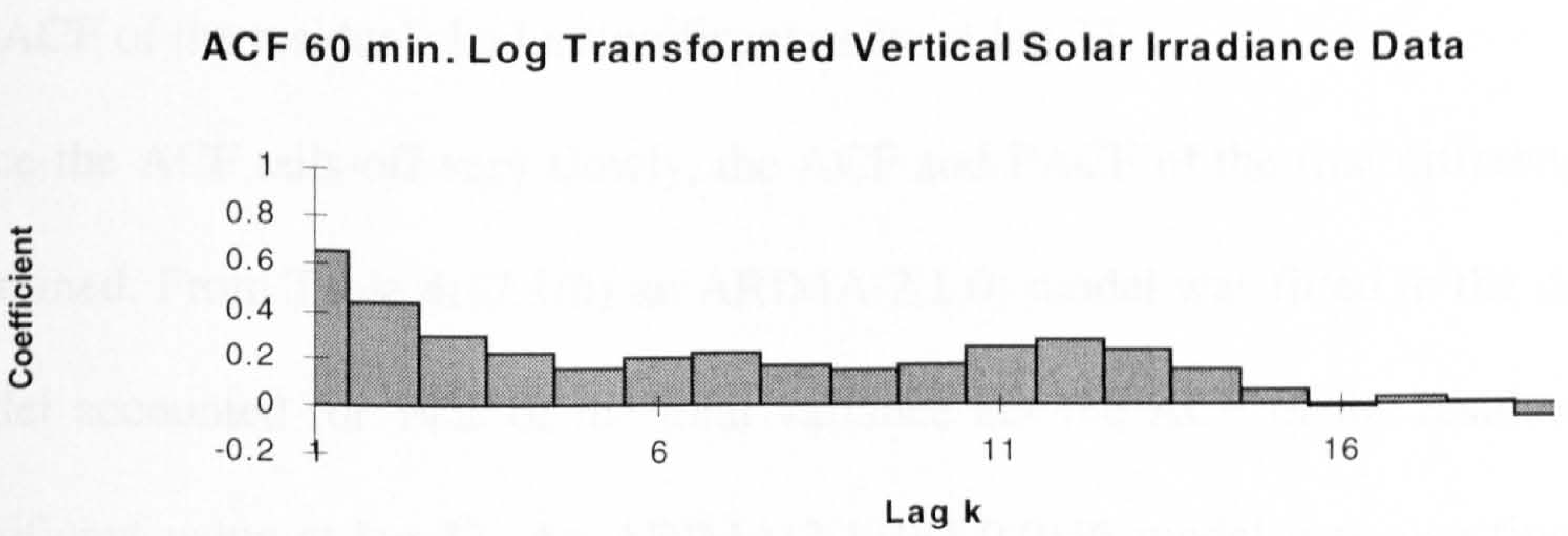


Figure 4.16.4 Log transformed Vertical Solar Irradiance - 60 minute averages, DEC94_60

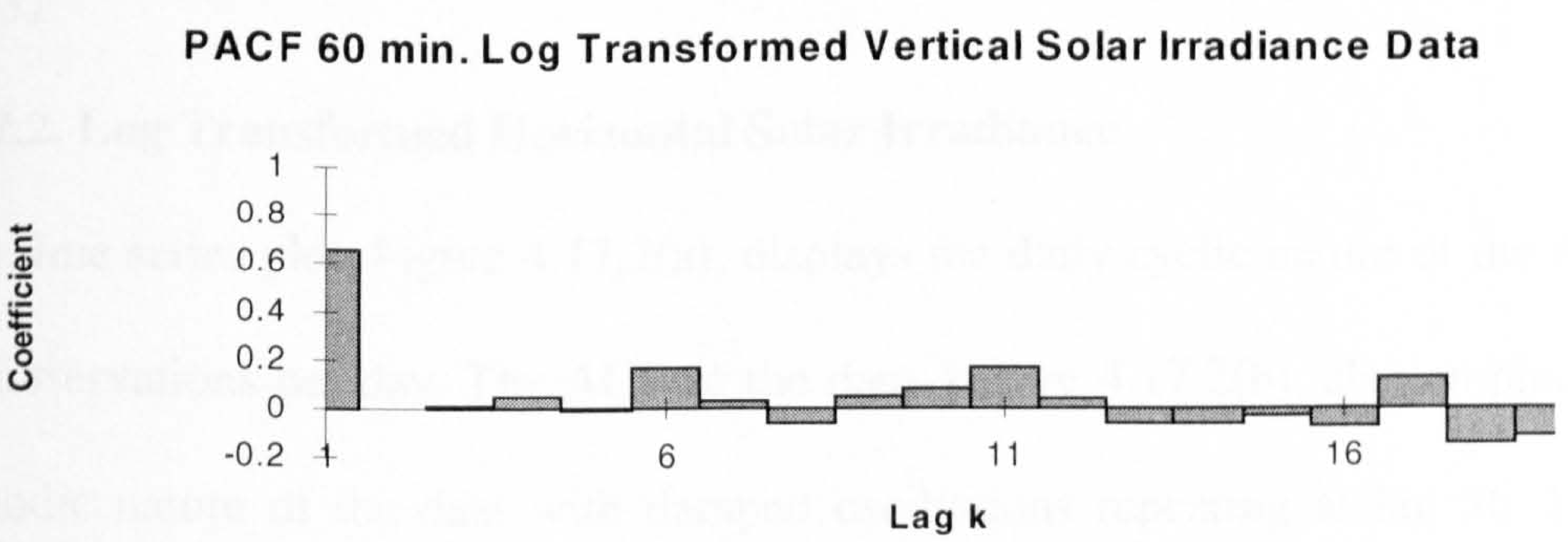
a)



b)



c)



4.17. December 1994 (16th - 31st) - Ten minute averages

This data set, known as DEC94_10, contains 10 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 16th and 31st December 1994.

4.17.1. Horizontal Solar Irradiance

The time series plot, Figure 4.17.1(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.17.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.17.1(b), and the structure of the ACF and PACF, Figure 4.17.1(b) & (c), an ARIMA(3,0,0) model was fitted to the data. This model accounted for 75% of the total variance but the ACF of the residuals had a significant value at lag 37. An ARIMA(3,0,0)(1,0,0)36 model was also fitted to the data, but this model also accounted for 75% of the total variance and the ACF of the residuals had a significant value at lag 37.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.17.1(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 74% of the total variance but the ACF of the residuals had a significant value at lag 37. An ARIMA(2,1,0)(1,0,0)36 model was also fitted to the data, which accounted for 74% of the total variance with a significant ACF value at lag 37.

4.17.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.17.2(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.17.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.17.2(b), and the structure of the ACF and PACF, Figure 4.17.2(b) & (c), an ARIMA(2,0,0)(1,0,0)36 model was fitted to the data. This model accounted for 83% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.17.2(b) an ARIMA(1,1,0)(1,0,0)36 model was fitted to the data. This model accounted for 82% of the total variance but the ACF of the residuals had a significant value at lag 2. An ARIMA(2,1,0)(1,0,0)36 model was then fitted to the data. This model was found to be appropriate, accounted for 82% of the total variance and the ACF of the residuals showed no structure.

4.17.3. Vertical Solar Irradiance

The time series plot, Figure 4.17.3(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.17.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.17.3(b), and the structure of the ACF and PACF, Figure 4.17.3(b) & (c), an ARIMA(3,0,0) model was fitted to the data. This model accounted for 78% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.17.3(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 77% of the total variance and the ACF of the residuals showed no structure.

4.17.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.17.4(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.17.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.17.4(b), and the structure of the ACF and PACF, Figure 4.17.4(b) & (c), an ARIMA(1,0,0)(1,0,0)36 model was fitted to the data. This model accounted for 81% of the total variance and the ACF of the showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.17.4(b), suggest fitting an ARIMA(2,1,0)(1,0,0)36 model was fitted to the data. This model accounted for 80% of the total variance and the ACF of the residuals showed no structure.

Table 4.17.1 Summary information for Horizontal Solar Irradiance - 10 minute averages (datafile DEC94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0793	0.0477	0.0028	0.2229

b)

$2/\sqrt{576} = 0.083$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.866	0.866	-0.050	-0.050
2	0.745	-0.019	-0.164	-0.167
3	0.669	0.110	0.001	-0.017
4	0.593	-0.031	0.031	0.002
36	0.310	0.027	0.007	-0.035

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1	0.8873	0.0415	21.36	0.31829	0.000556	75
	AR2	-0.1155	0.0554	-2.08			
	AR3	0.1109	0.0416	2.67			
	CONST	0.0091	0.0009	9.28			
ARIMA(2,1,0)	AR1	-0.0579	0.0412	-1.40	0.33457	0.000584	74
	AR2	-0.1674	0.0412	-4.06			
ARIMA(2,1,0)(1,0,0)36	AR1	-0.0685	0.0412	-1.66	0.33387	0.000584	74
	AR2	-0.1749	0.0412	-4.24			
	SAR36	0.0478	0.0424	1.13			

Table 4.17.2 Summary information for Log Transformed Horizontal Solar Irradiance - 10 minute averages (datafile DEC94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.7882	0.8173	-5.8781	-1.5010

b)

$2/\sqrt{576} = 0.083$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.905	0.905	0.097	0.097
2	0.793	-0.146	-0.021	-0.081
3	0.696	0.029	0.009	0.025
4	0.599	-0.075	-0.020	-0.030
36	0.308	-0.004	0.114	0.076

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)	AR1	1.0465	0.0413	25.34	66.0095	0.1152	83
	AR2	-0.1509	0.0413	-3.66			
	CONST	-0.2936	0.0142	-20.75			
ARIMA(2,0,0)(1,0,0)36	AR1	1.0183	0.0416	24.48	65.1819	0.1140	83
	AR2	-0.1269	0.0416	-3.05			
	SAR36	0.1340	0.0453	2.95			
	CONST	-0.2642	0.0141	-18.77			
ARIMA(1,1,0)(1,0,0)36	AR1	0.0737	0.0418	1.77	69.3079	0.1210	82
	SAR36	0.1265	0.0454	2.78			
ARIMA(2,1,0)(1,0,0)36	AR1	0.0768	0.0417	1.84	68.5357	0.1198	82
	AR2	-0.1044	0.0418	-2.50			
	SAR36	0.1488	0.0456	3.26			

Table 4.17.3 Summary information for Vertical Solar Irradiance - 10 minute averages (datafile DEC94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2383	0.2249	0.0022	0.7524

b)

$2/\sqrt{576} = 0.083$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.884	0.884	-0.085	-0.085
2	0.788	0.031	-0.133	-0.141
3	0.723	0.097	0.008	-0.017
4	0.657	-0.022	0.008	-0.012
36	0.056	0.060	0.046	-0.022

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1	0.8569	0.0416	20.59	6.23802	0.01091	78
	AR2	-0.0520	0.0549	-0.95			
	AR3	0.0953	0.0416	2.29			
	CONST	0.0231	0.0043	5.31			
ARIMA(2,1,0)	AR1	-0.0976	0.0414	-2.36	6.50118	0.01135	77
	AR2	-0.1414	0.0414	-3.42			

Table 4.17.4 Summary information for Log Transformed Vertical Solar Irradiance - 10 minute averages (datafile DEC94_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.1700	1.4681	-6.1193	-0.2845

b)

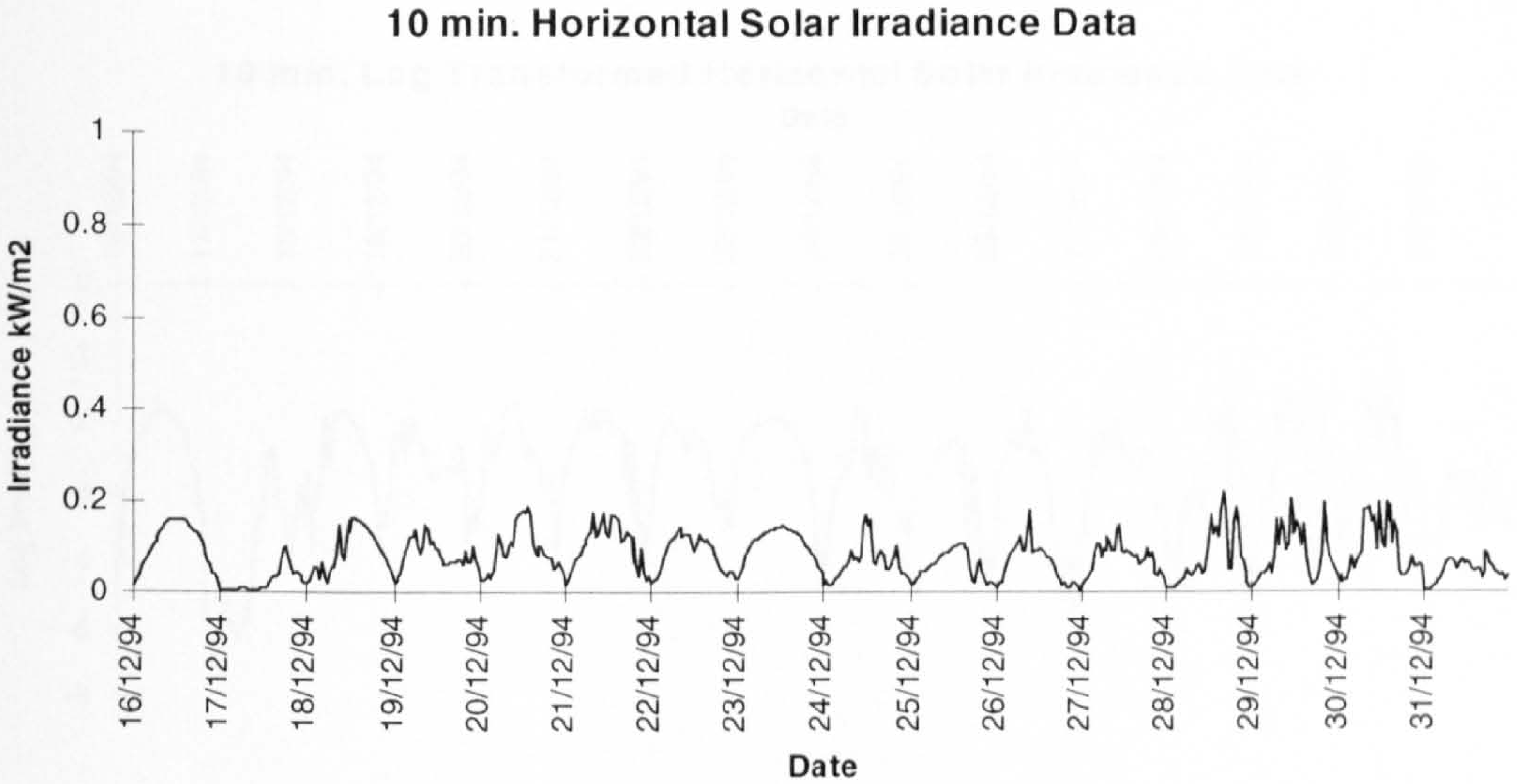
$2/\sqrt{576} = 0.083$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.900	0.900	0.002	0.002
2	0.800	-0.048	-0.112	-0.112
3	0.724	0.067	-0.011	-0.011
4	0.651	-0.032	-0.013	-0.026
36	0.112	0.091	0.120	0.088

c)

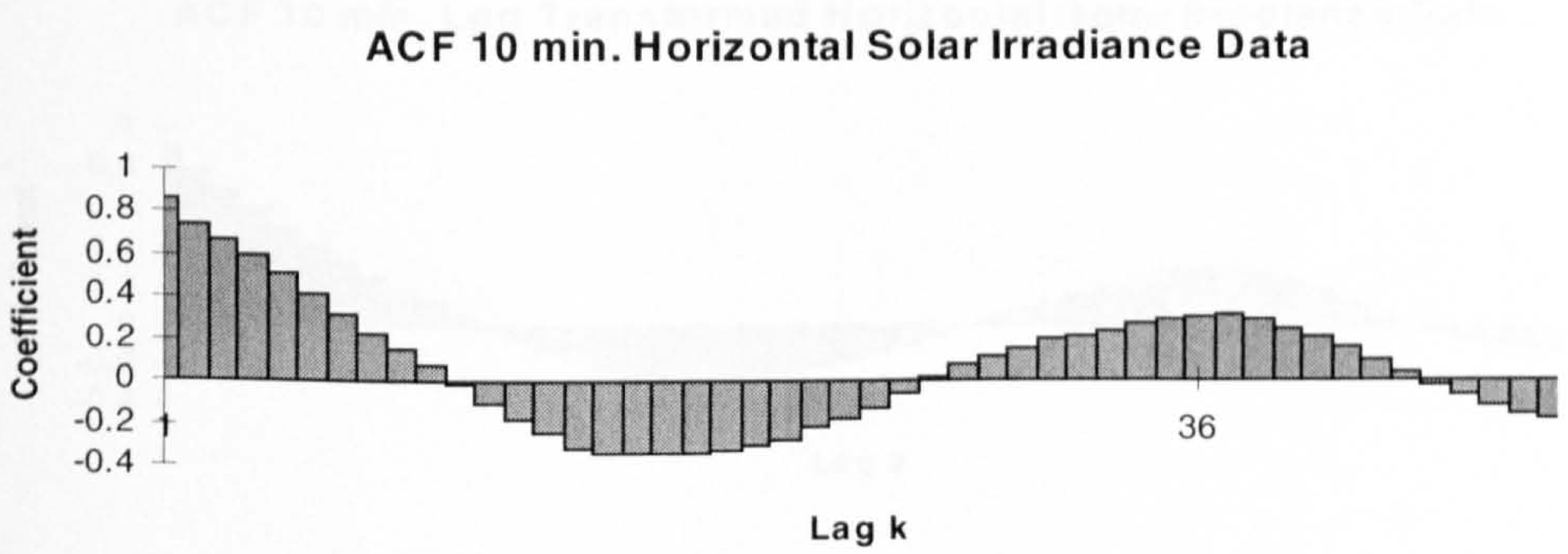
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)36	AR1	0.9012	0.0181	49.68	229.958	0.401	81
	SAR36	0.1417	0.0427	3.31			
	CONST	-0.1863	0.0264	-7.05			
ARIMA(2,1,0)(1,0,0)36	AR1	0.0055	0.0415	0.13	237.492	0.415	80
	AR2	-0.1305	0.0415	-3.14			
	SAR36	0.1542	0.0427	3.61			

Figure 4.17.1 Horizontal Solar Irradiance - 10 minute averages, DEC94_10

a)



b)



c)

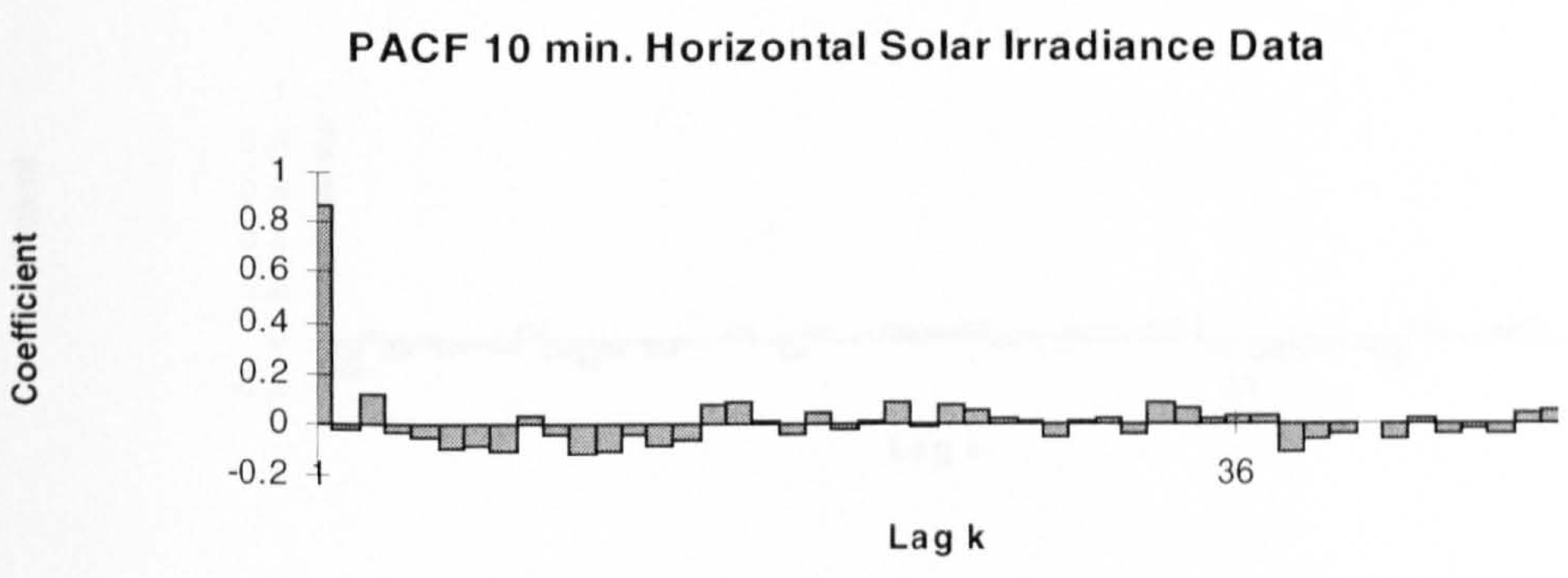
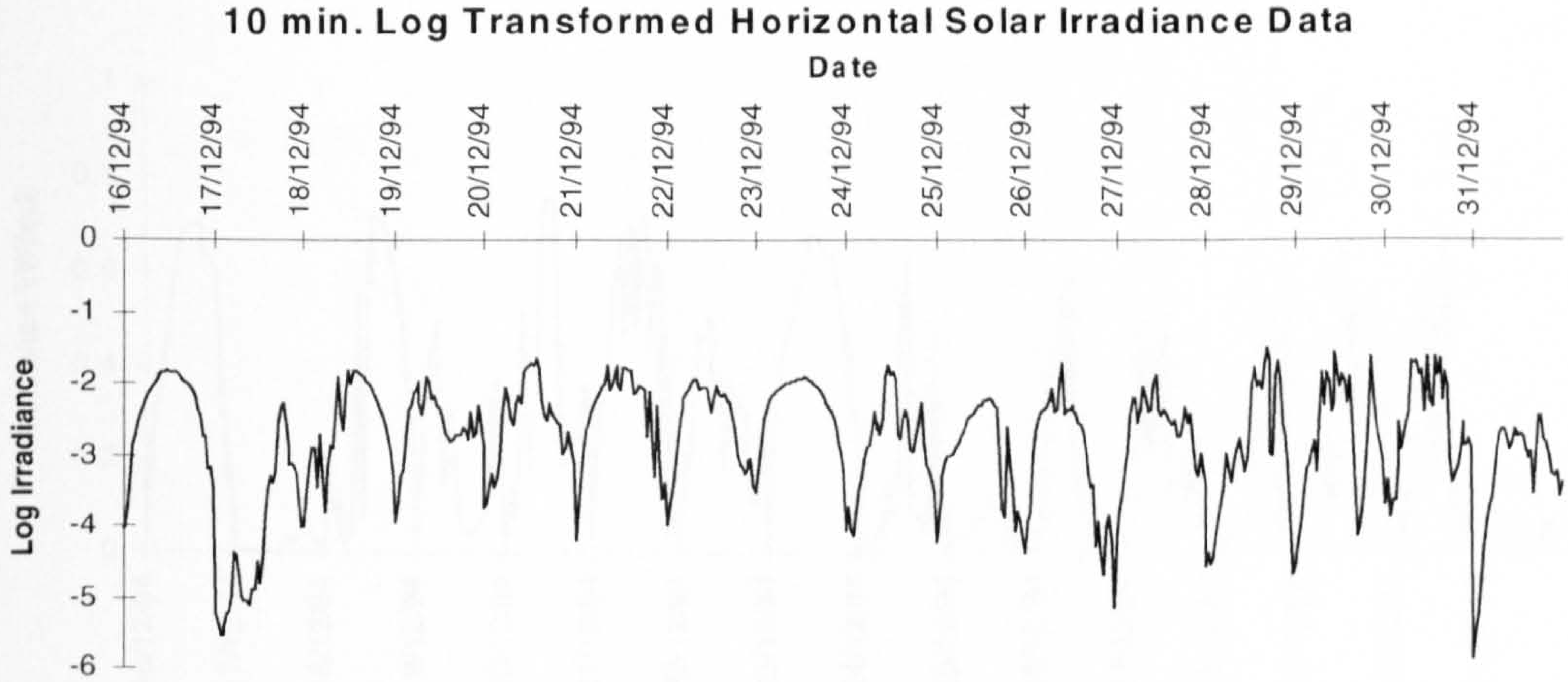
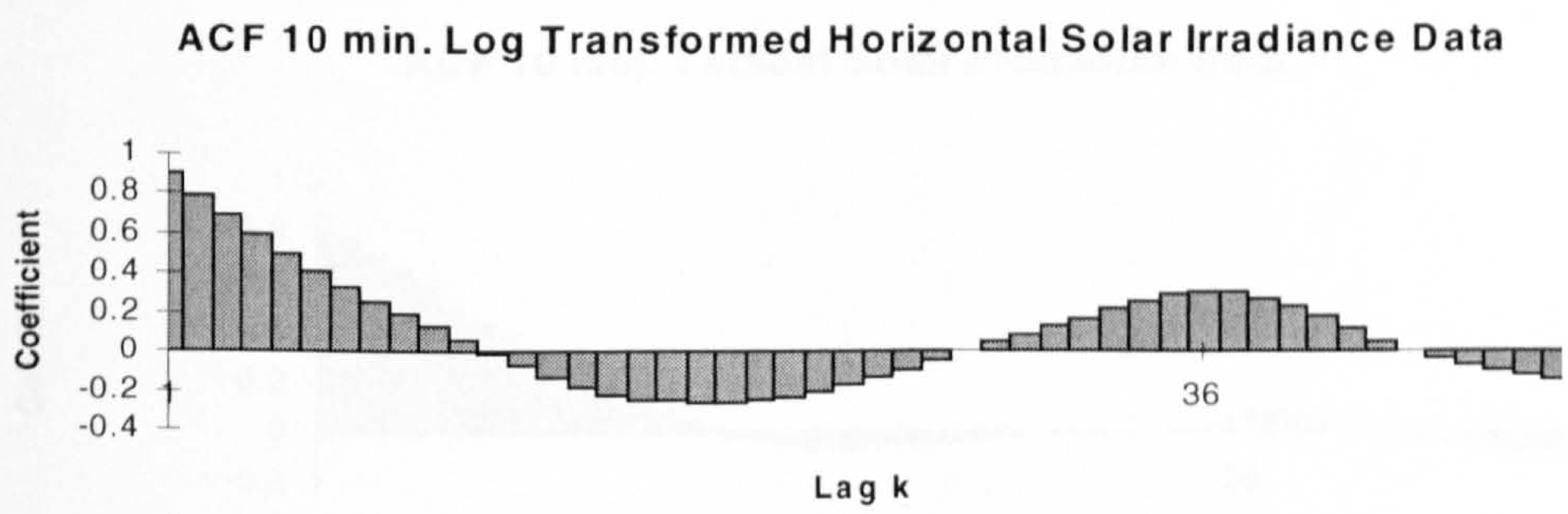


Figure 4.17.2 Log transformed Horizontal Solar Irradiance - 10 minute averages, DEC94_10

a)



b)



c)

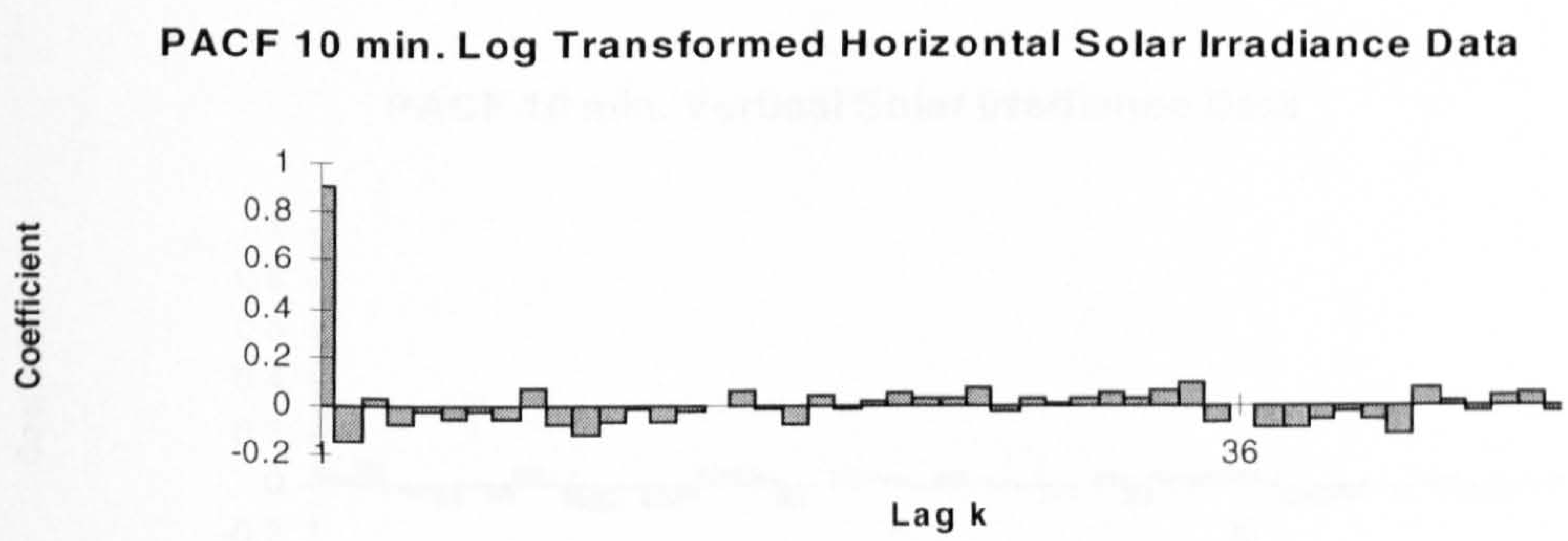
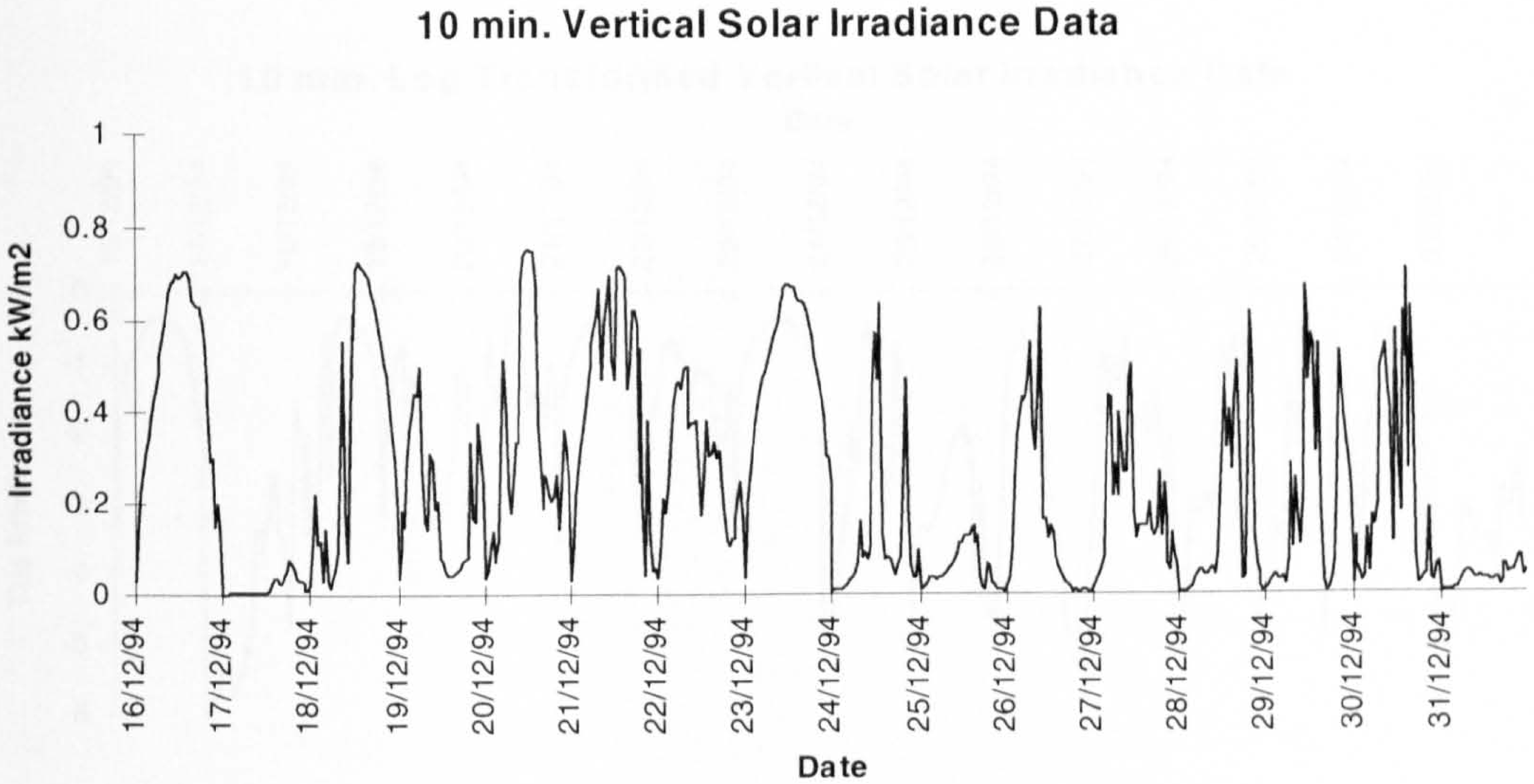
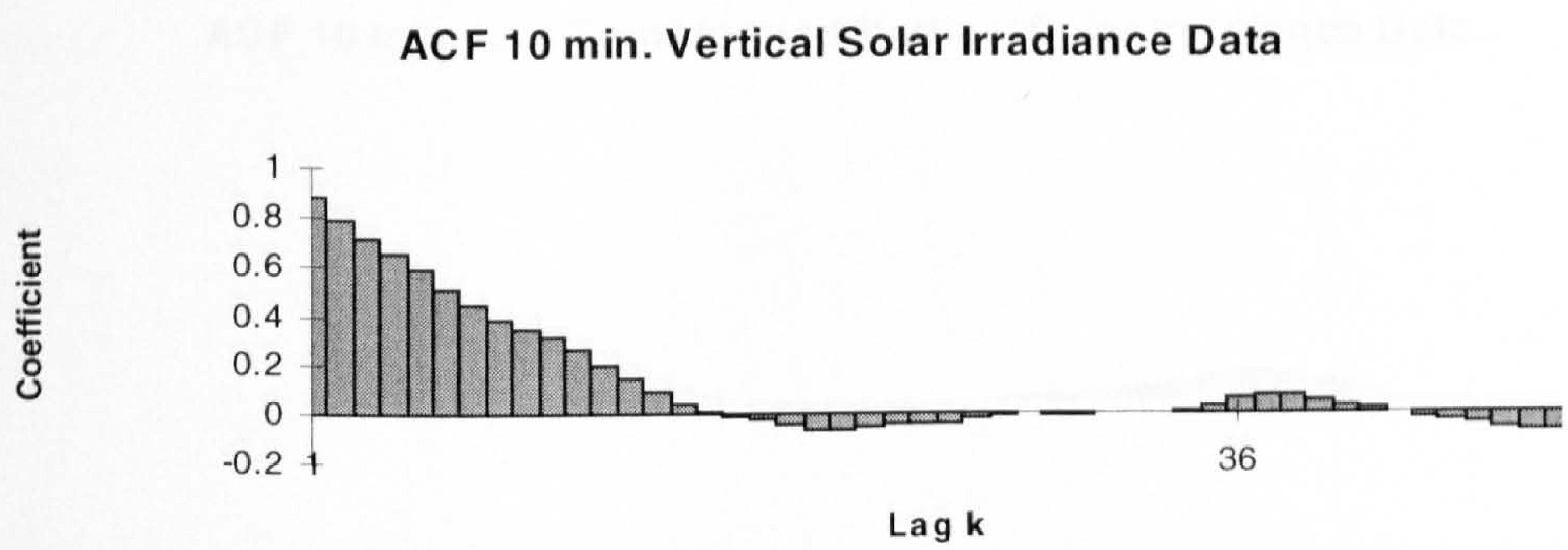


Figure 4.17.3 Vertical Solar Irradiance - 10 minute averages, DEC94_10

a)



b)



c)

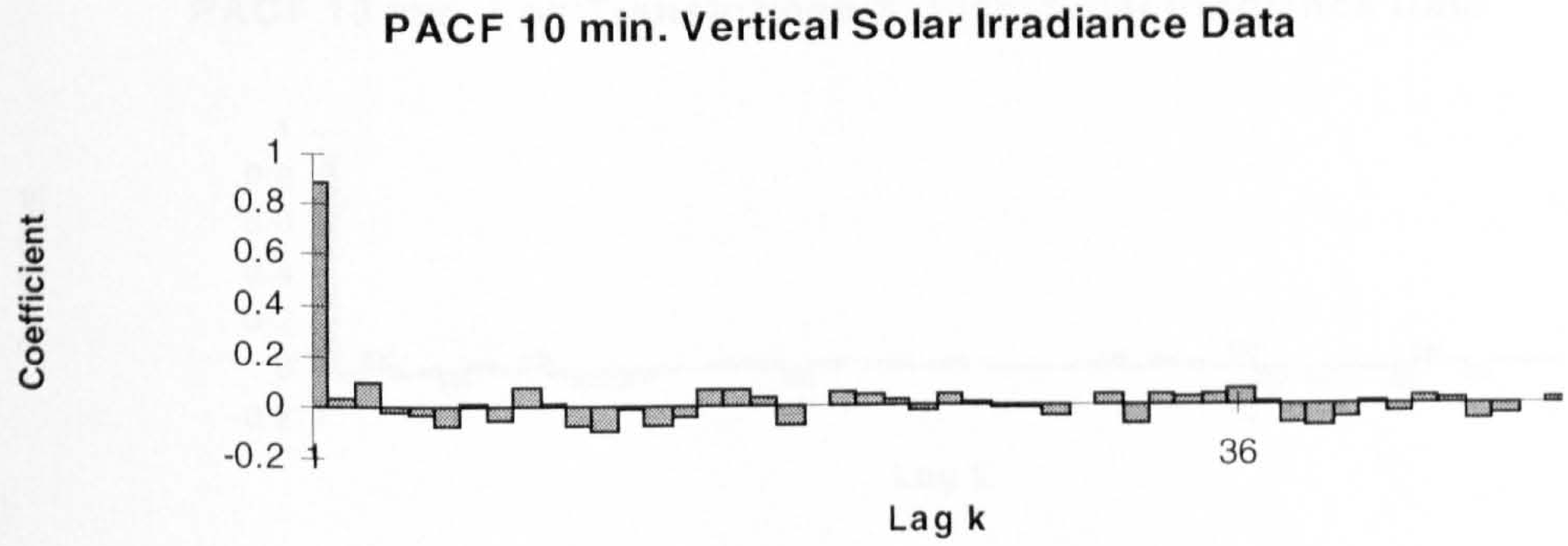
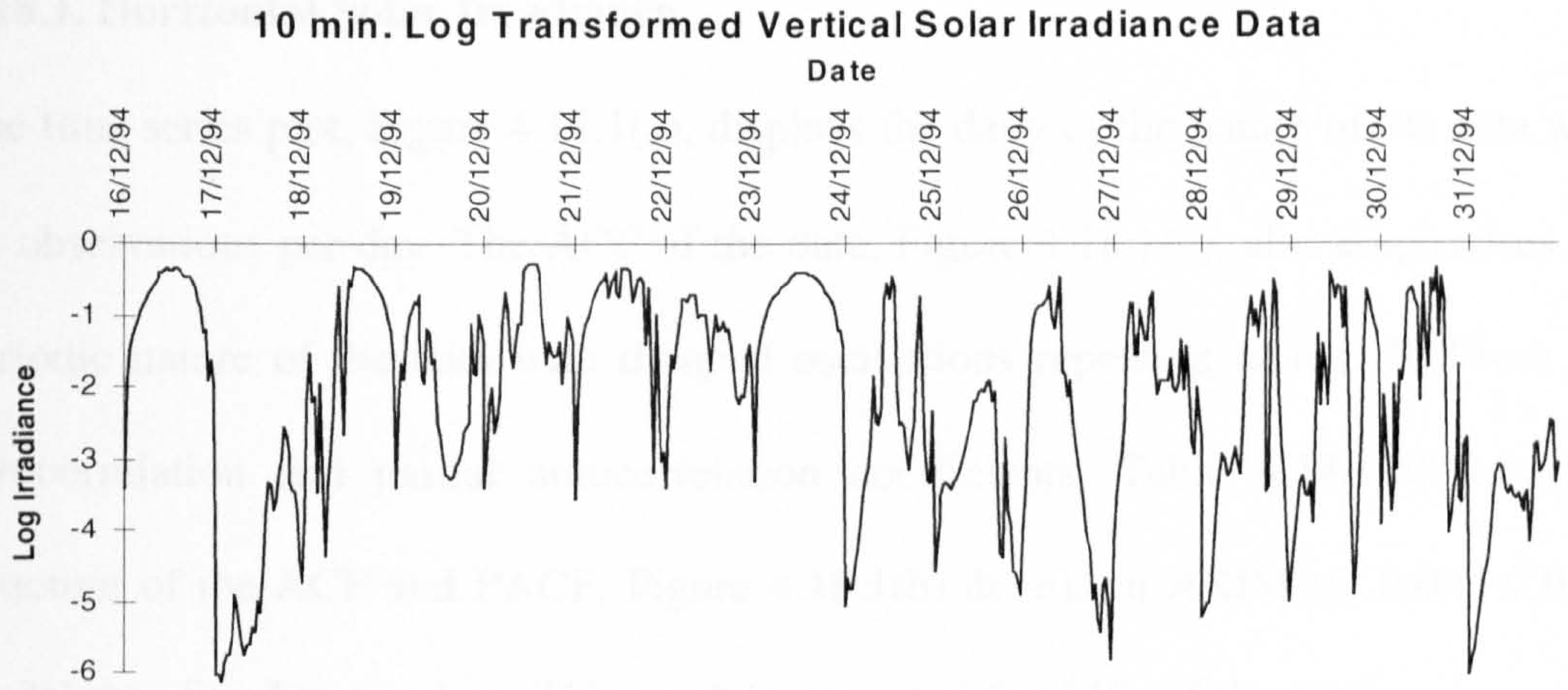
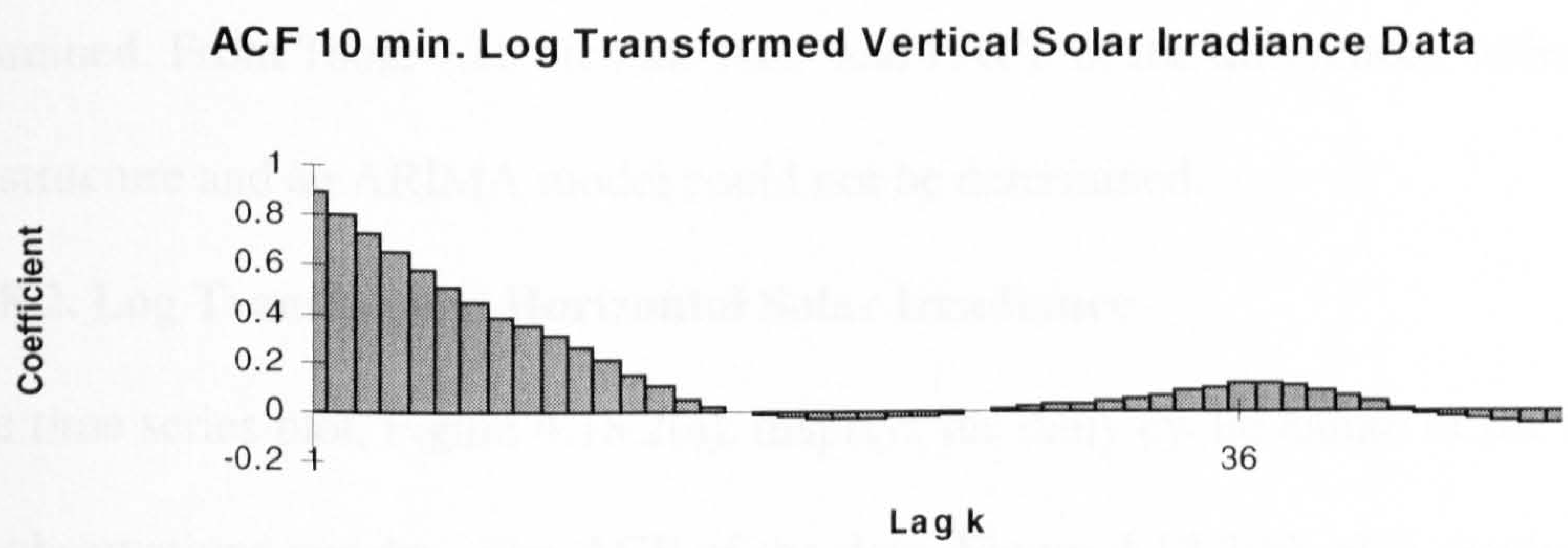


Figure 4.17.4 Log transformed Vertical Solar Irradiance - 10 minute averages, DEC94_10

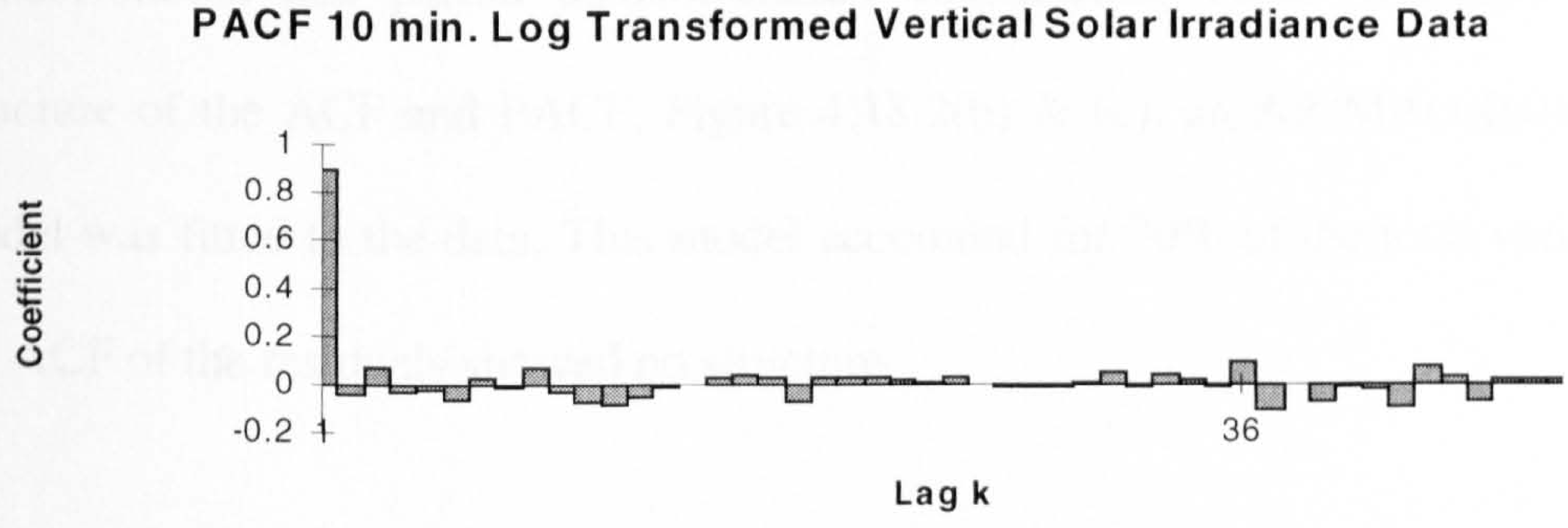
a)



b)



c)



4.18. December 1994 (16th - 31st) - Twenty minute averages

This data set, known as DEC94_20, contains 20 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 16th and 31st December 1994.

4.18.1. Horizontal Solar Irradiance

The time series plot, Figure 4.18.1(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.18.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.18.1(b), and the structure of the ACF and PACF, Figure 4.18.1(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model accounted for 64% of the total variance but the ACF of the residuals had significant values.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.18.1(b) the ACF and PACF of the differenced series showed no structure and an ARIMA model could not be determined.

4.18.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.18.2(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.18.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.18.2(b), and the structure of the ACF and PACF, Figure 4.18.2(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model accounted for 70% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.18.2(b) the ACF and the PACF of the differenced series showed no structure and an ARIMA model could not be determined.

4.18.3. Vertical Solar Irradiance

The time series plot, Figure 4.18.3(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.18.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.18.3(b), the structure of the ACF and PACF, Figure 4.18.3(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model was found to be appropriate, accounted for 71% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.18.3(b) the ACF and the PACF of the differenced series showed no structure and an ARIMA model could not be determined.

4.18.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.18.4(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.18.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.18.4(b), and the structure of the ACF and PACF, Figure 4.18.4(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 69% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.18.4(b) the ACF and PACF of the differenced series showed no structure and an ARIMA model could not be determined.

Table 4.18.1 Summary information for Horizontal Solar Irradiance - 20 minute averages (datafile DEC94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0793	0.0463	0.0033	0.2000

b)

$2/\sqrt{288} = 0.118$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.796	0.796	-0.078	-0.078
2	0.627	-0.021	0.055	0.049
3	0.438	-0.150	0.038	0.046
4	0.238	-0.171	-0.097	-0.094
18	0.328	0.041	0.143	0.044

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)18	AR1	0.7920	0.0366	21.65	0.21432	0.000752	64
	SAR18	0.1765	0.0594	2.97			
	CONST	0.0134	0.0016	8.27			

Table 4.18.2 Summary information for Log Transformed Horizontal Solar Irradiance - 20 minute averages (datafile DEC94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.7777	0.8024	-5.6988	-1.6094

b)

$2/\sqrt{288} = 0.118$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.819	0.819	0.071	0.071
2	0.618	-0.159	-0.029	-0.034
3	0.430	-0.080	-0.051	-0.047
4	0.264	-0.070	-0.127	-0.122
18	0.311	-0.073	0.220	0.107

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)18	AR1	0.8115	0.0344	23.57	55.3403	0.1942	70
	SAR18	0.2956	0.0622	4.76			
	CONST	-0.3671	0.0259	-14.13			
ARIMA(0,1,0)(1,0,0)18	SAR18	0.2948	0.0624	4.72	60.6815	0.2122	67

Table 4.18.3 Summary information for Vertical Solar Irradiance - 20 minute averages (datafile DEC94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2383	0.2184	0.0024	0.7508

b)

$2/\sqrt{288} = 0.118$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.844	0.844	-0.015	-0.015
2	0.696	-0.060	-0.001	-0.001
3	0.548	-0.084	-0.053	-0.053
4	0.417	-0.036	-0.124	-0.126
18	0.056	0.057	0.091	0.017

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8480	0.0315	26.90	3.88501	0.01358	71
	CONST	0.0352	0.0069	5.13			
ARIMA(1,0,0)(1,0,0)18	AR1	0.8485	0.0315	26.91	3.85195	0.01352	71
	SAR18	0.0940	0.0593	1.59			
	CONST	0.0318	0.0069	4.65			

Table 4.18.4 Summary information for Log Transformed Vertical Solar Irradiance - 20 minute averages (datafile DEC94_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.1354	1.4420	-6.0323	-0.2867

b)

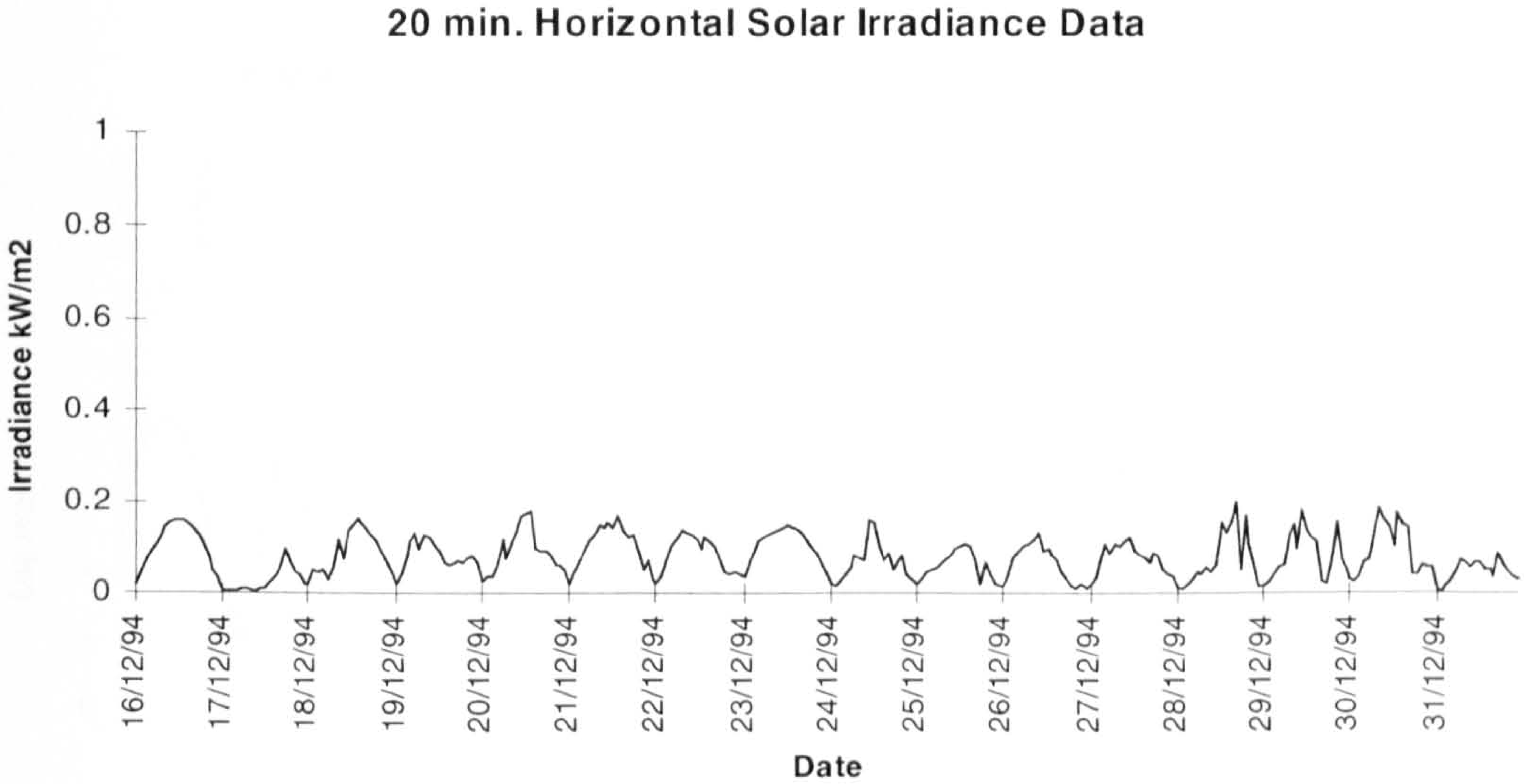
$2/\sqrt{288} = 0.118$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.832	0.832	-0.037	-0.037
2	0.677	-0.047	-0.019	-0.020
3	0.528	-0.072	-0.075	-0.077
4	0.405	-0.015	-0.129	-0.137
18	0.098	-0.019	0.086	0.010

c)

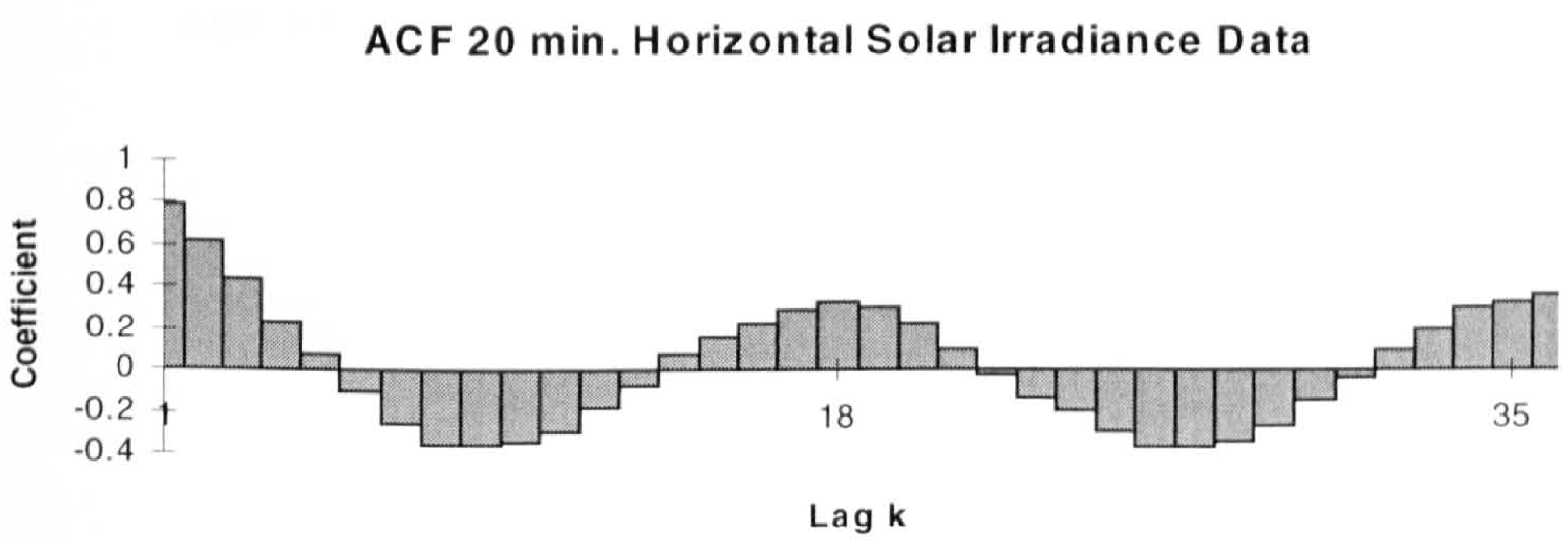
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8332	0.0328	25.40	183.294	0.641	69
	CONST	-0.3600	0.0472	-7.63			
ARIMA(1,0,0)(1,0,0)18	AR1	0.8326	0.0329	25.30	181.586	0.637	69
	SAR18	0.1047	0.0612	1.71			
	CONST	-0.3227	0.0471	-6.86			

Figure 4.18.1 Horizontal Solar Irradiance - 20 minute averages, DEC94_20

a)



b)



c)

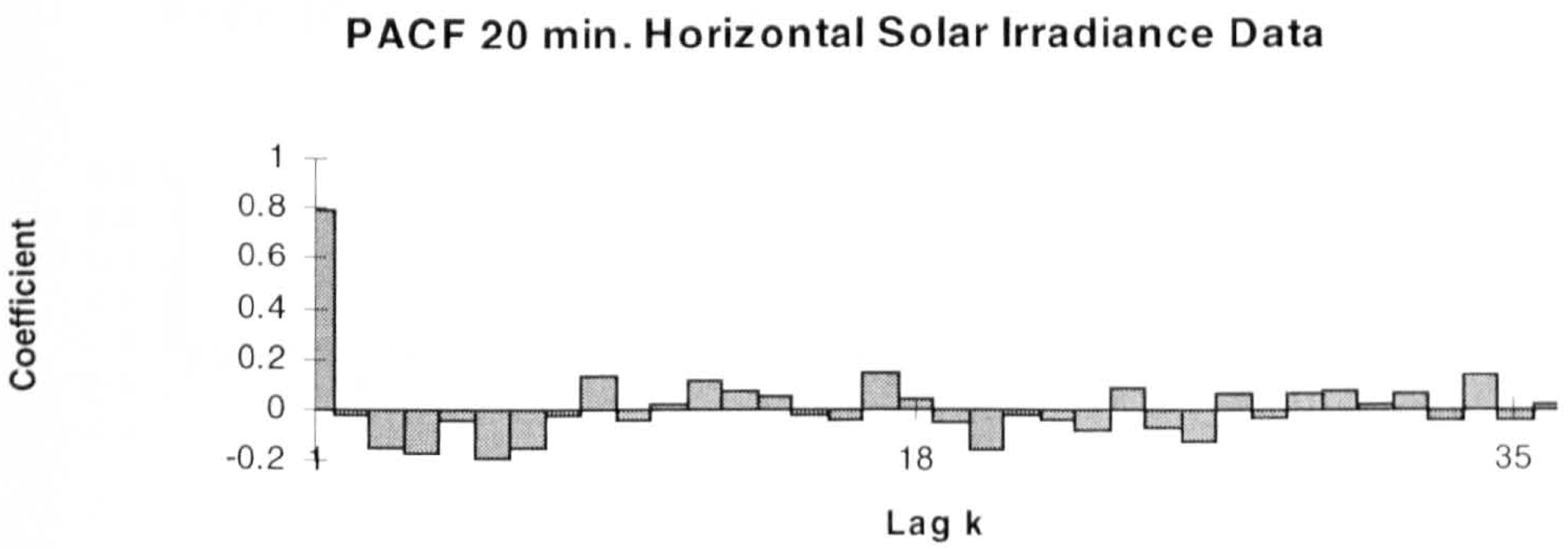
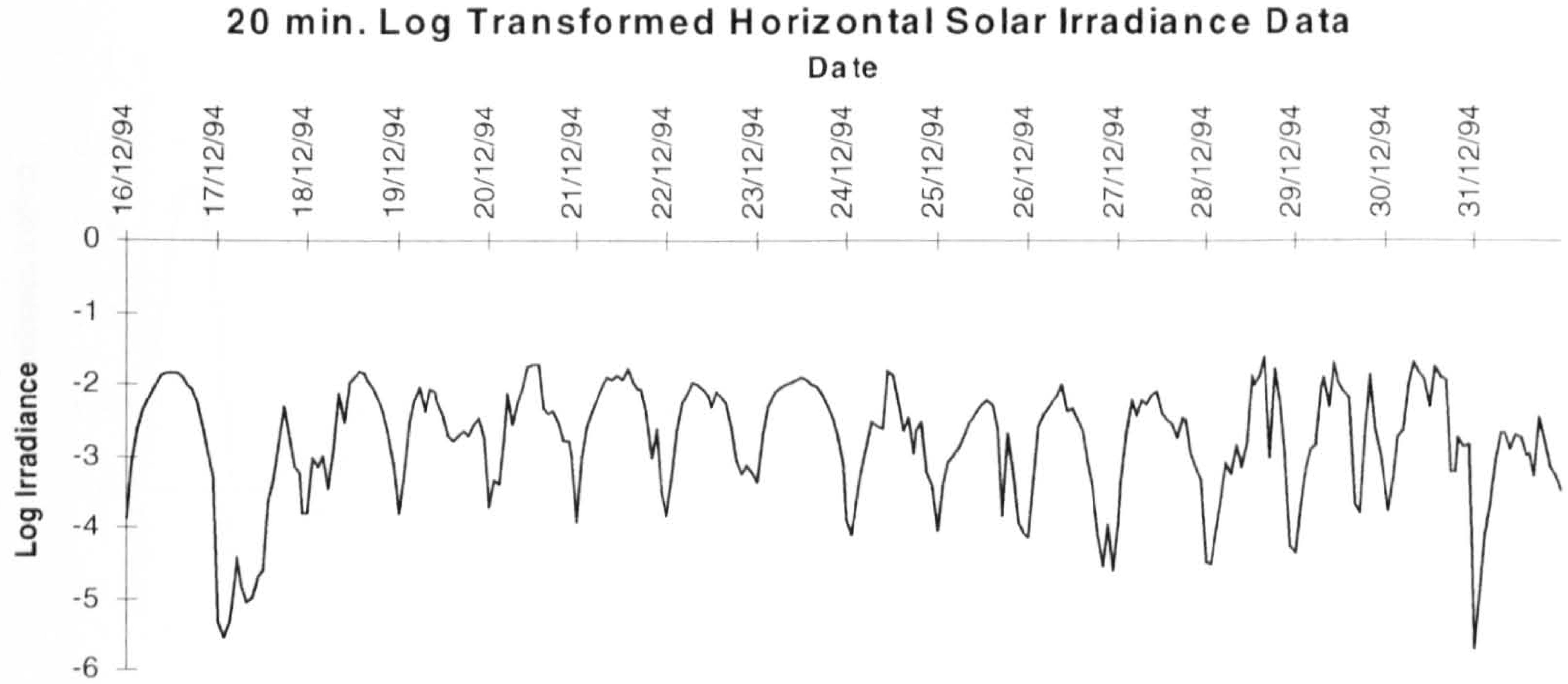
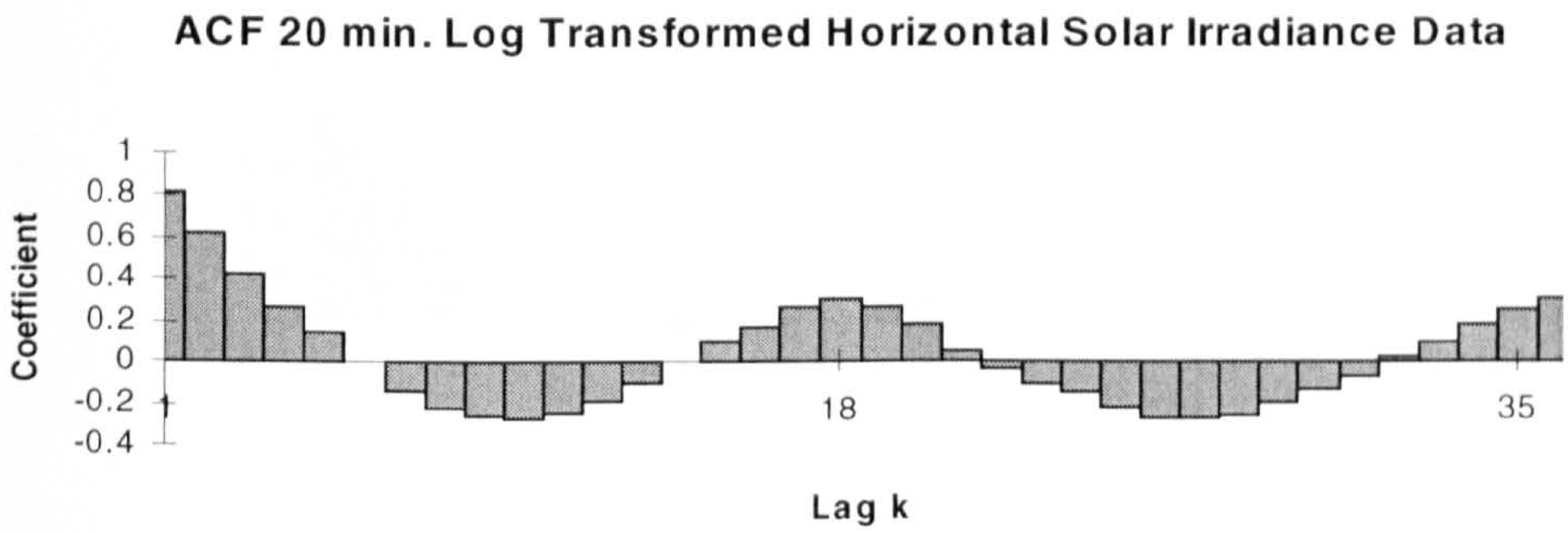


Figure 4.18.2 Log transformed Horizontal Solar Irradiance - 20 minute averages, DEC94_20

a)



b)



c)

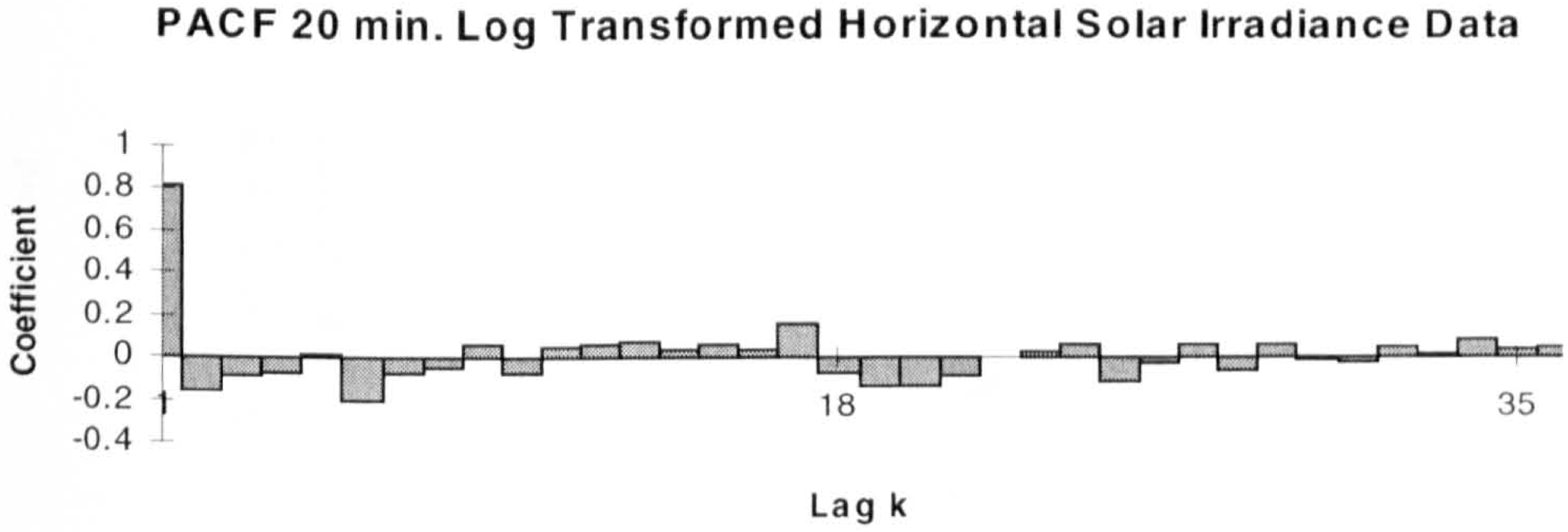
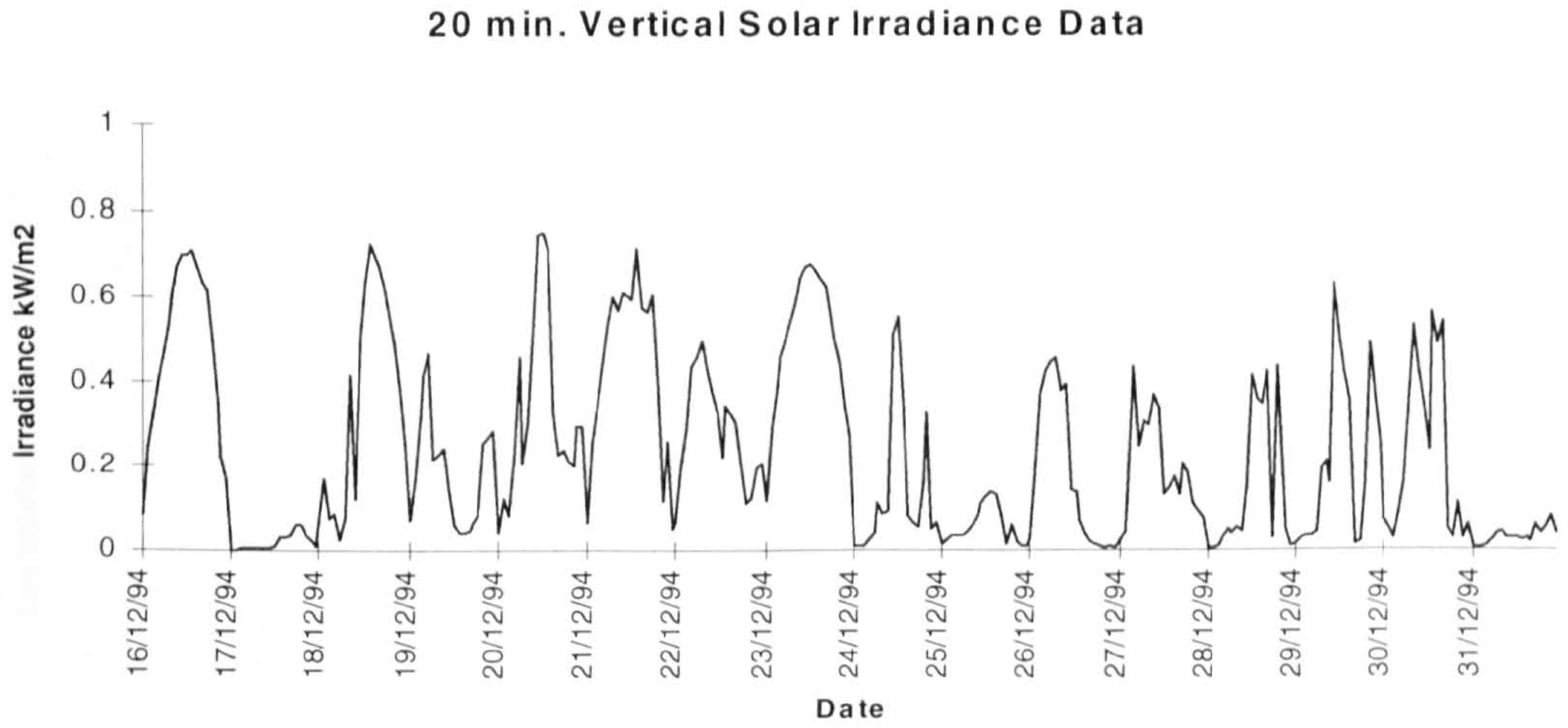
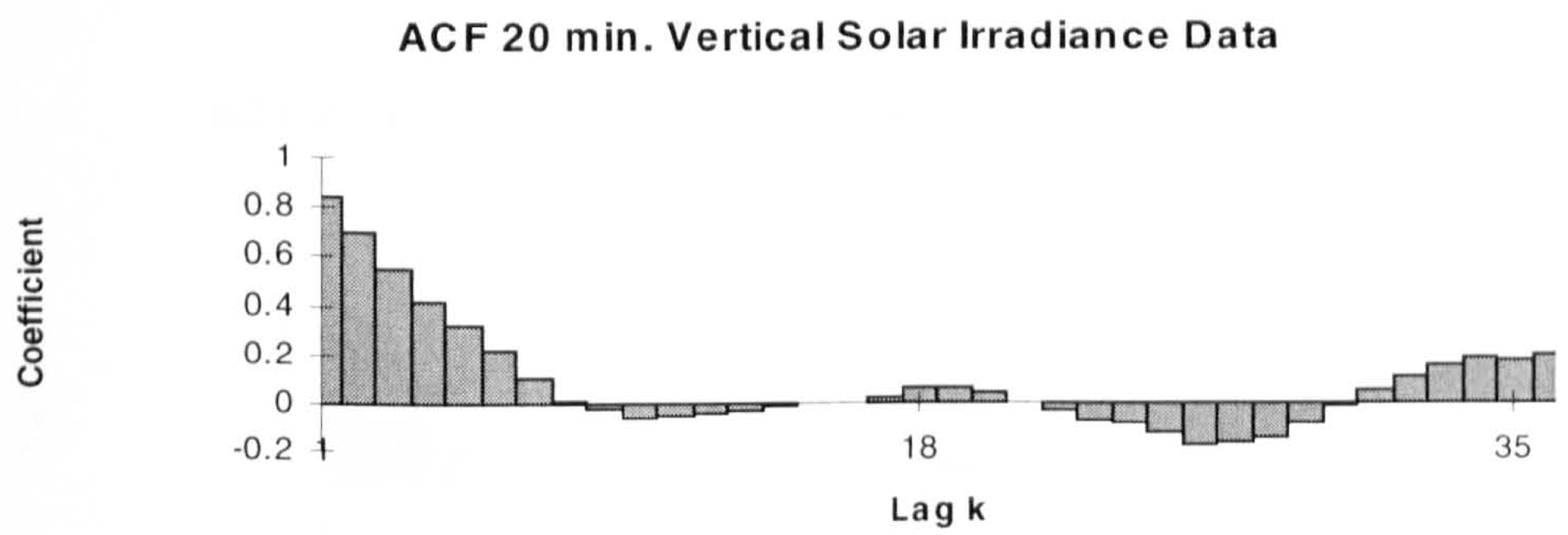


Figure 4.18.3 Vertical Solar Irradiance - 20 minute averages, DEC94_20

a)



b)



c)

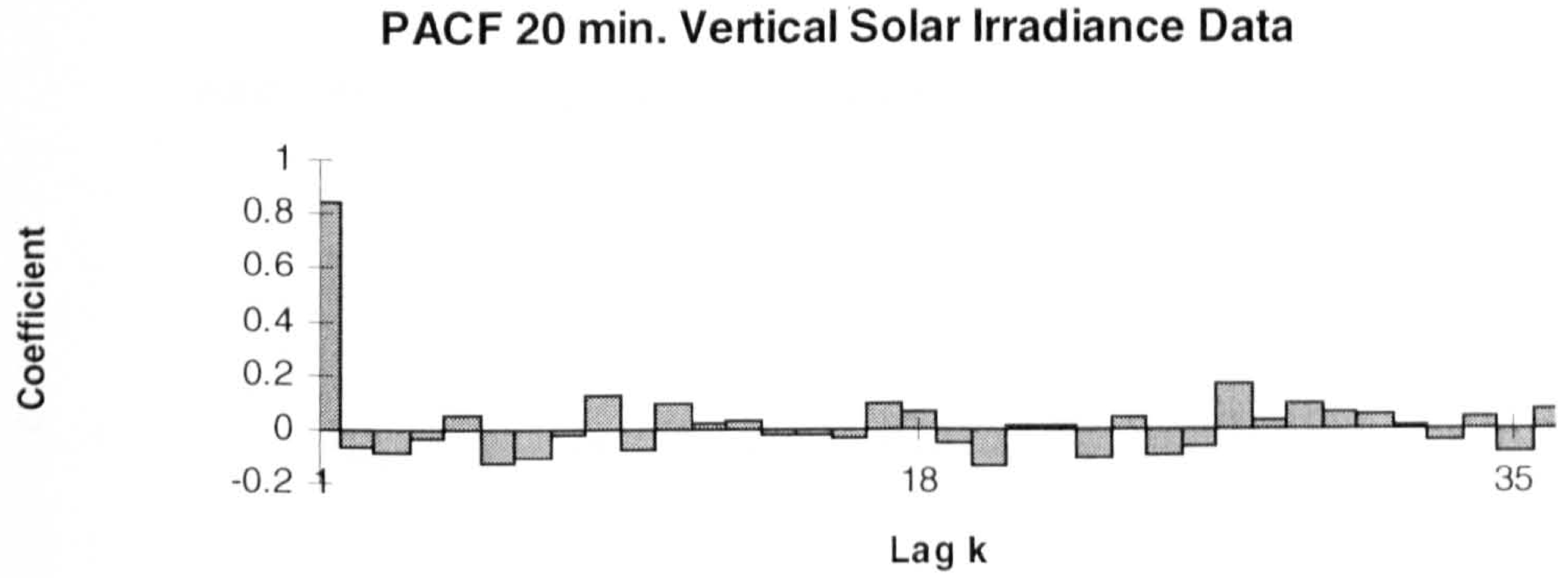
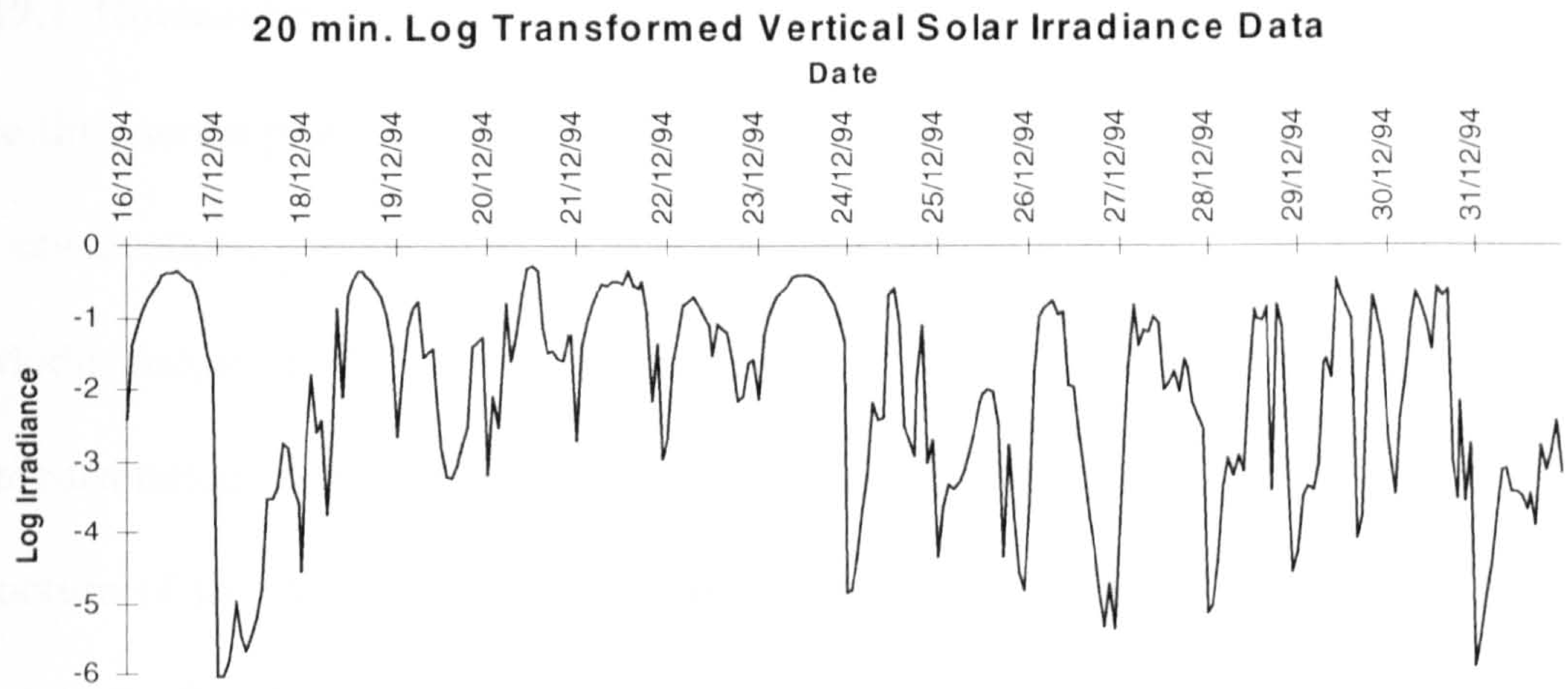
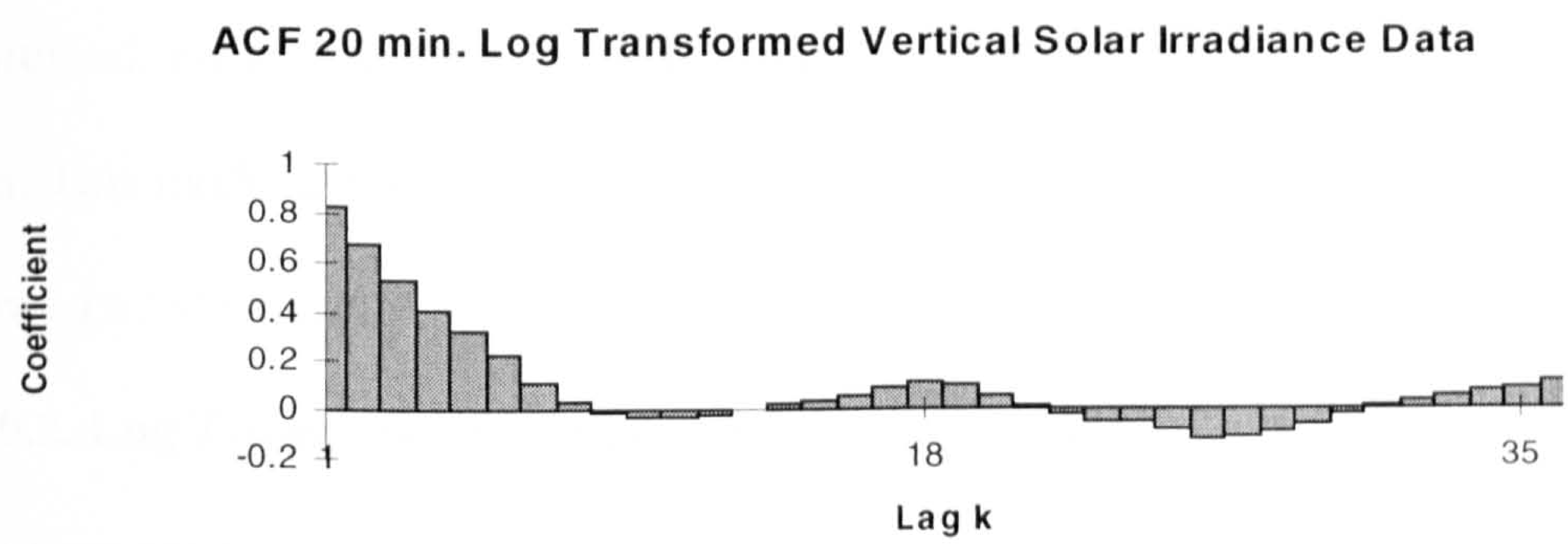


Figure 4.18.4 Log transformed Vertical Solar Irradiance - 20 minute averages, DEC94_20

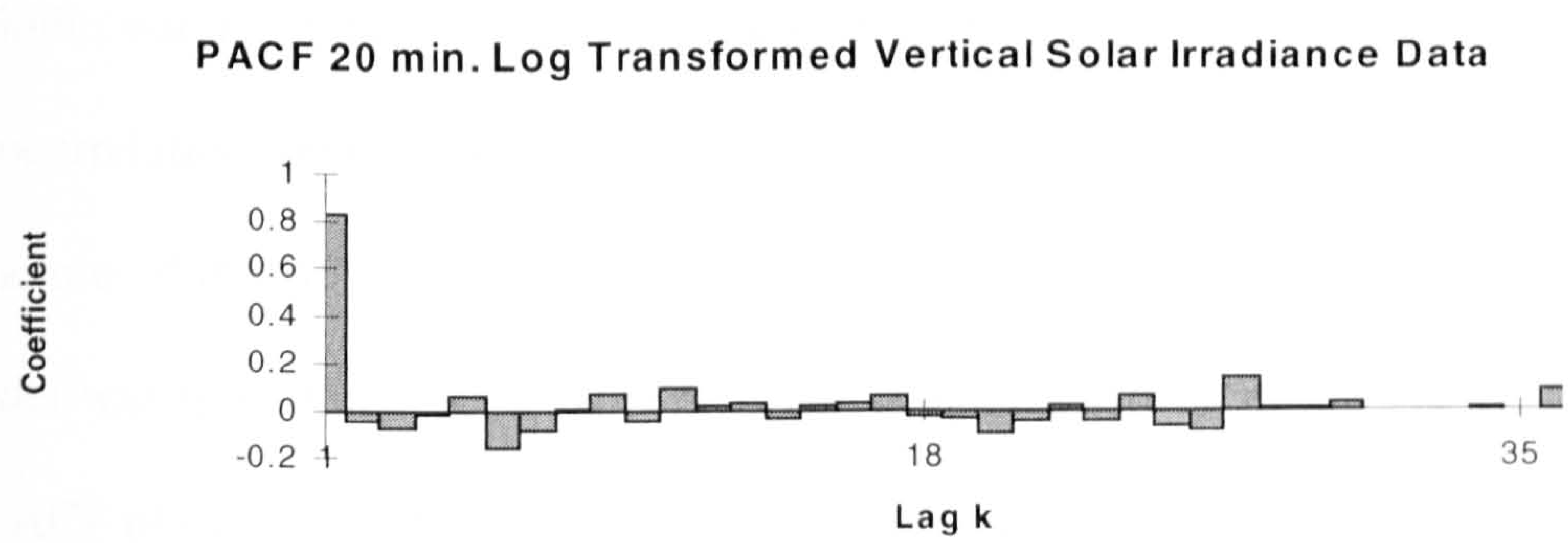
a)



b)



c)



4.19. December 1994 (16th - 31st) - Thirty minute averages

This data set, known as DEC94_30, contains 30 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 16th and 31st December 1994.

4.19.1. Horizontal Solar Irradiance

The time series plot, Figure 4.19.1(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.19.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.19.1(b), and the structure of the ACF and PACF, Figure 4.19.1(b) & (c), an ARIMA(1,1,0)(1,0,0)12 model was fitted to the data. This model accounted for 65% of the total variance but the ACF of the residuals had a significant value at lag 1.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.19.1(b) an ARIMA(1,1,0)(1,0,0)12 model was fitted to the data. This model accounted for 62% of the total variance and the ACF of the residuals showed no structure.

4.19.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.19.2(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.19.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.19.2(b), and the structure of the ACF and PACF, Figure 4.19.2(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model accounted for 64% of the total variance but the ACF of the residuals had a significant value at lag 1.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.19.2(b) an ARIMA(1,1,0)(1,0,0)12 model was fitted to the data. This model also accounted for 59% of the total variance and the ACF of the residuals showed no structure.

4.19.3. Vertical Solar Irradiance

The time series plot, Figure 4.19.3(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.19.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.19.3(b), and the structure of the ACF and PACF, Figure 4.19.3(b) & (c), an ARIMA(2,0,0) model was fitted to the data. This model accounted for 70% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.19.3(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 66% of the total variance and the ACF of the residuals showed no structure.

4.19.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.19.4(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.19.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.19.4(b), and the structure of the ACF and PACF, Figure 4.19.4(b) & (c), an ARIMA(2,0,0) model was fitted to the data. This model accounted for 64% of the total variance but the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.19.4(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 59% of the total variance and the ACF of the residuals showed no structure.

Table 4.19.1 Summary information for Horizontal Solar Irradiance - 30 minute averages (datafile DEC94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0793	0.0448	0.0040	0.1809

b)

$2/\sqrt{194} = 0.144$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.784	0.784	0.263	0.263
2	0.466	-0.389	-0.029	-0.105
3	0.167	-0.109	-0.030	0.006
4	-0.118	-0.250	-0.178	-0.189
12	0.336	0.027	0.255	0.052

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)12	AR1	0.7799	0.0457	17.07	0.13179	0.000697	65
	SAR12	0.2976	0.0707	4.21			
	CONST	0.01192	0.0019	6.25			
ARIMA(1,1,0)(1,0,0)12	AR1	0.1968	0.0715	2.75	0.14413	0.000763	62
	SAR12	0.2001	0.0728	2.75			

Table 4.19.2 Summary information for Log Transformed Horizontal Solar Irradiance - 30 minute averages (datafile DEC94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.7642	0.7807	-5.5215	-1.7098

b)

$2/\sqrt{194} = 0.144$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.759	0.759	0.162	0.162
2	0.450	-0.297	-0.131	-0.161
3	0.209	-0.024	-0.057	-0.007
4	-0.006	-0.177	-0.086	-0.100
12	0.309	0.004	0.317	0.159

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)12	AR1	0.7731	0.0463	16.70	41.4203	0.2192	64
	SAR12	0.4277	0.0733	5.83			
	CONST	-0.3607	0.0338	-10.67			
ARIMA(1,1,0)(1,0,0)12	AR1	0.0549	0.0722	0.76	46.5207	0.2461	59
	SAR12	0.4076	0.0745	5.47			

Table 4.19.3 Summary information for Vertical Solar Irradiance - 30 minute averages (datafile DEC94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2383	0.2136	0.0023	0.7501

b)

$2/\sqrt{194} = 0.144$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.818	0.818	0.188	0.188
2	0.572	-0.297	-0.166	-0.208
3	0.385	0.072	-0.063	0.015
4	0.222	-0.135	-0.015	-0.042
12	0.047	0.042	0.085	0.028

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,1,0)	AR1	0.1901	0.0712	2.67	3.00641	0.01582	65
ARIMA(2,1,0)	AR1	0.2287	0.0711	3.22	2.87500	0.01521	66
	AR2	-0.2100	0.0711	-2.95			
ARIMA(1,0,0)(1,0,0)12	AR1	0.8223	0.0415	19.80	2.82187	0.01493	67
	SAR12	0.0923	0.0728	1.27			
	CONST	0.0374	0.0088	4.24			

Table 4.19.4 Summary information for Log Transformed Vertical Solar Irradiance - 30 minute averages (datafile DEC94_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.1000	1.4100	-6.060	-0.288

b)

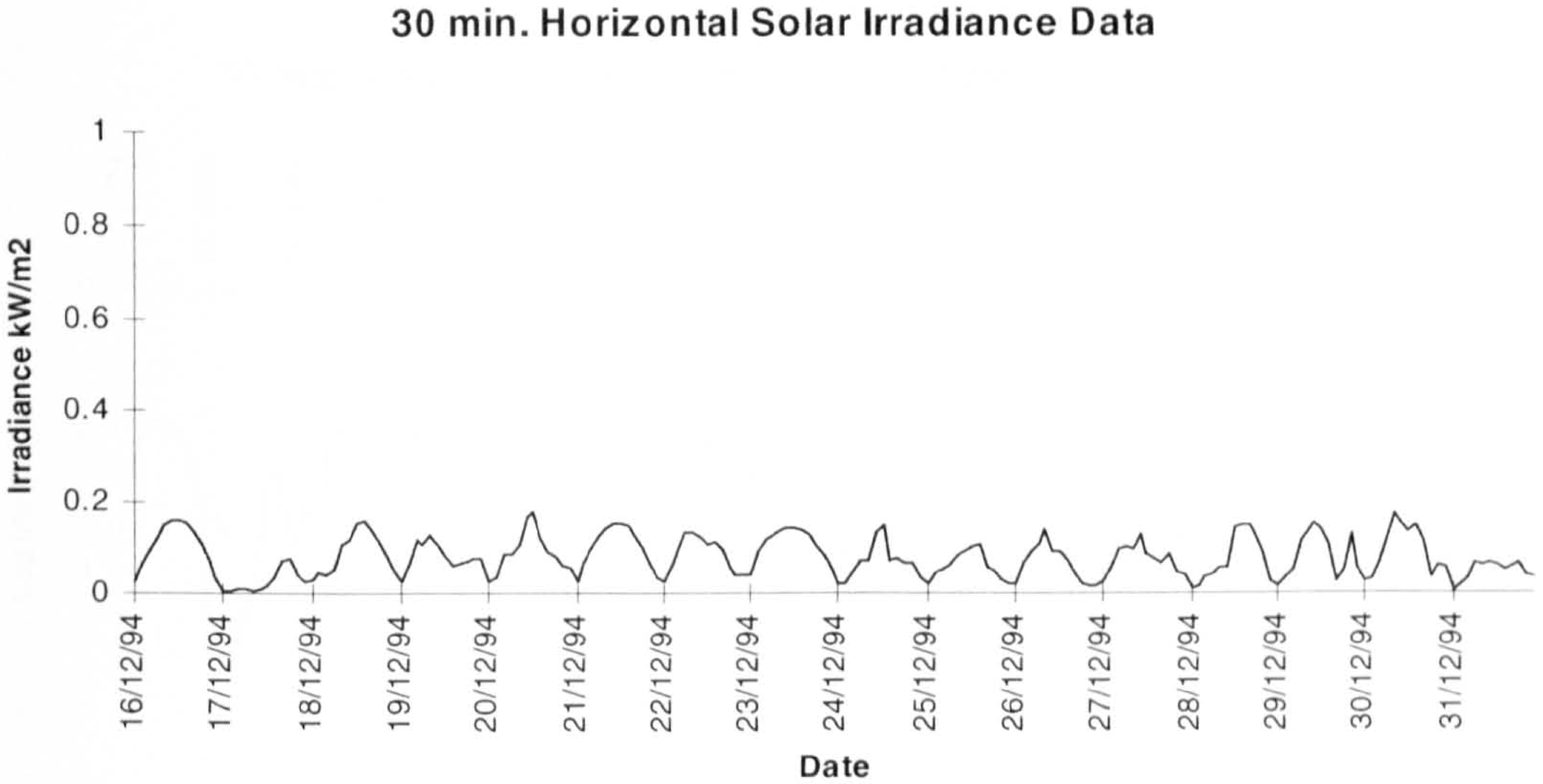
$2/\sqrt{194} = 0.144$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.791	0.791	0.088	0.088
2	0.545	-0.214	-0.176	-0.186
3	0.372	0.051	-0.057	-0.024
4	0.222	-0.101	0.006	-0.019
12	0.078	-0.076	0.067	-0.059

c)

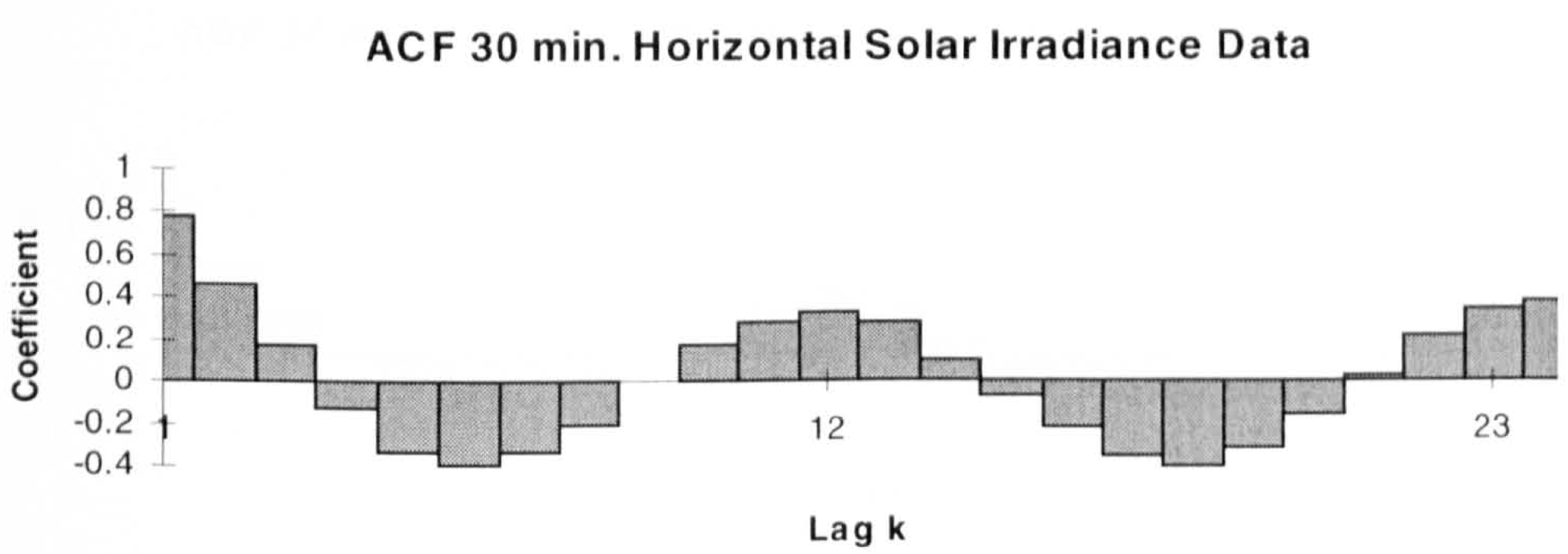
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)	AR1	0.9624	0.0711	13.55	135.420	0.717	64
	AR2	-0.2157	0.0711	-3.03			
	CONST	-0.5347	0.0611	-8.75			
ARIMA(2,1,0)	AR1	0.1042	0.0715	1.46	151.717	0.803	59
	AR2	-0.1865	0.0715	-2.61			
ARIMA(1,0,0)(1,0,0)12	AR1	0.7916	0.0445	17.77	141.124	0.747	62
	SAR12	0.0823	0.0753	1.09			
	CONST	-0.4033	0.0624	-6.47			

Figure 4.19.1 Horizontal Solar Irradiance - 30 minute averages, DEC94_30

a)



b)



c)

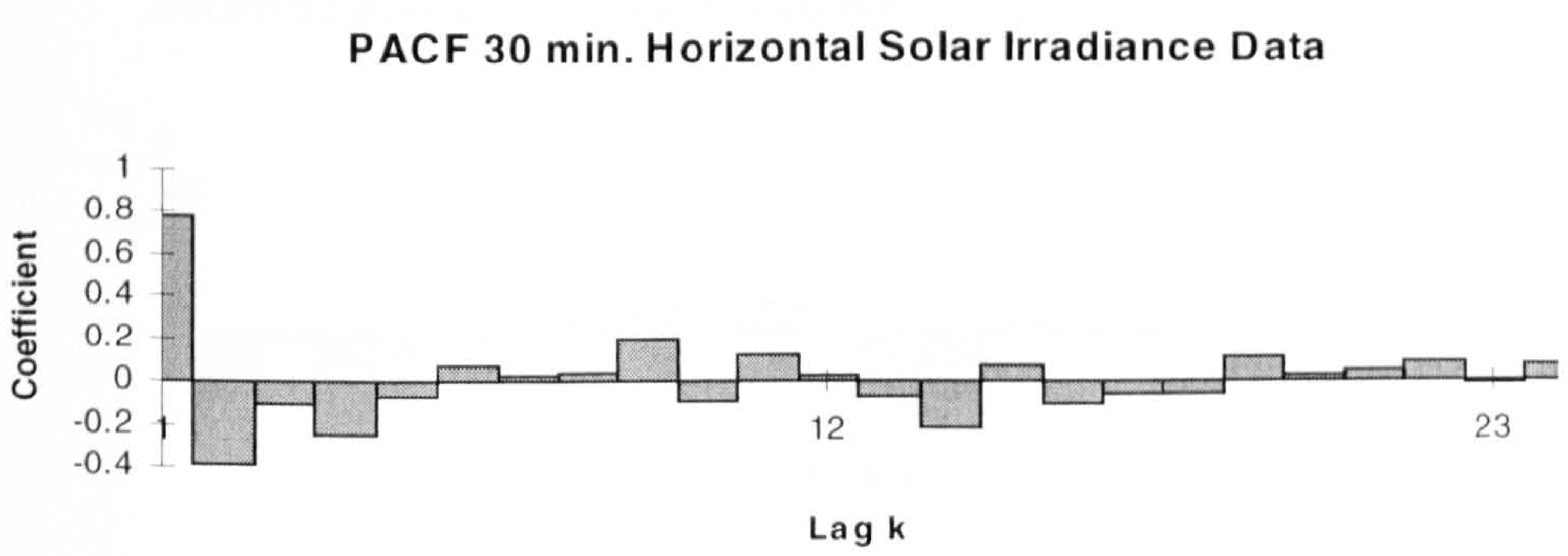
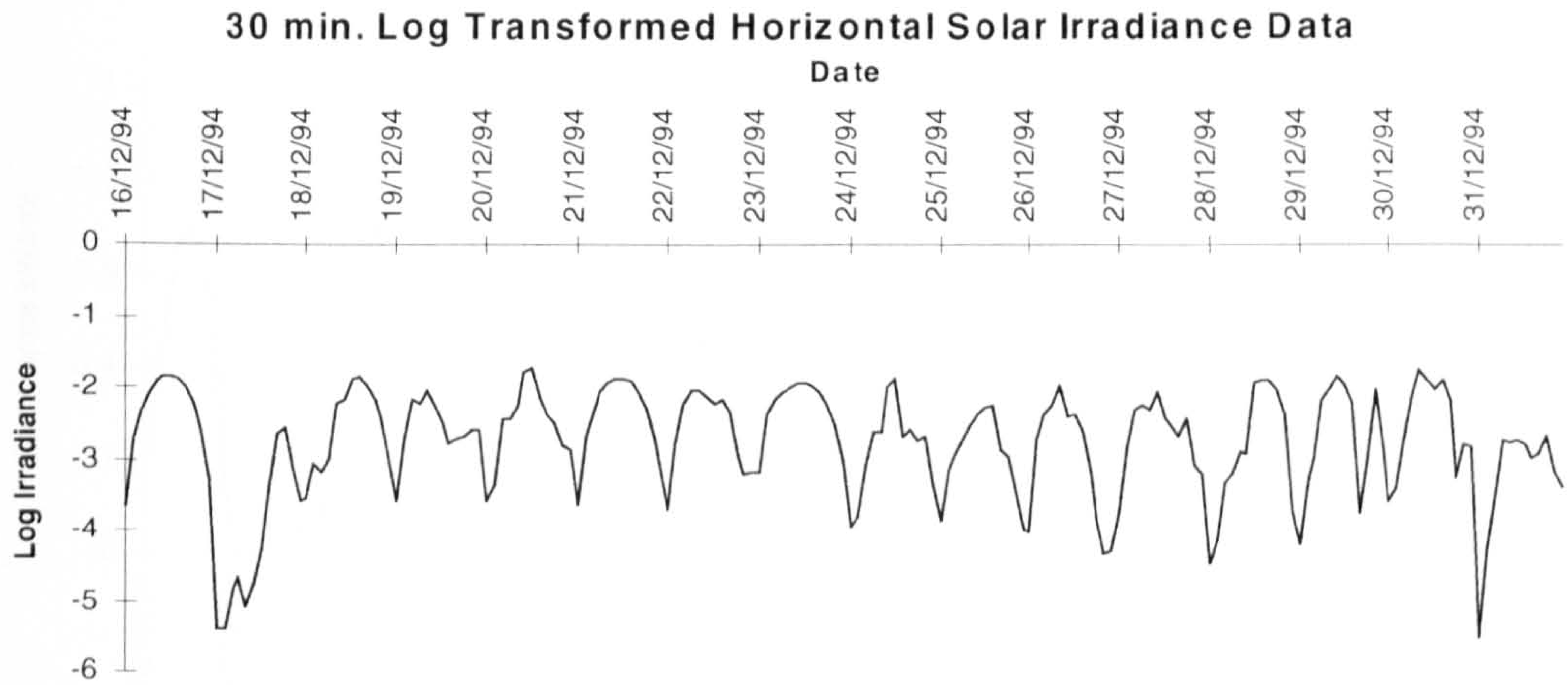
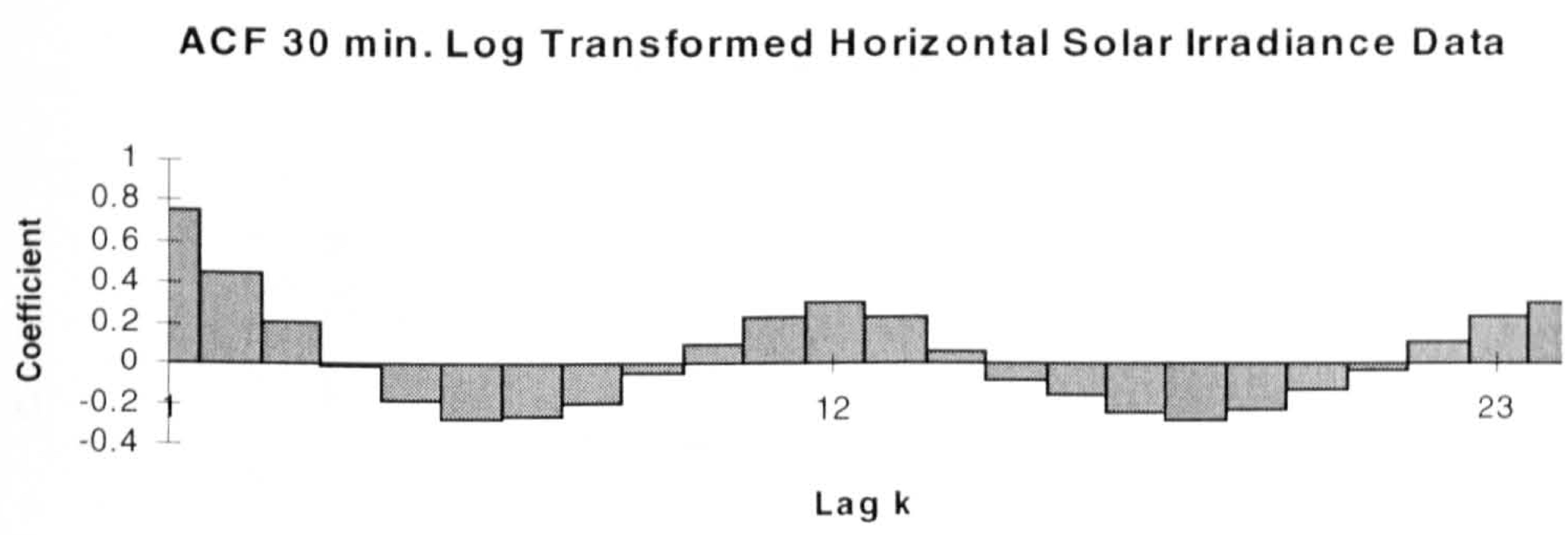


Figure 4.19.2 Log transformed Horizontal Solar Irradiance - 30 minute averages, DEC94_30

a)



b)



c)

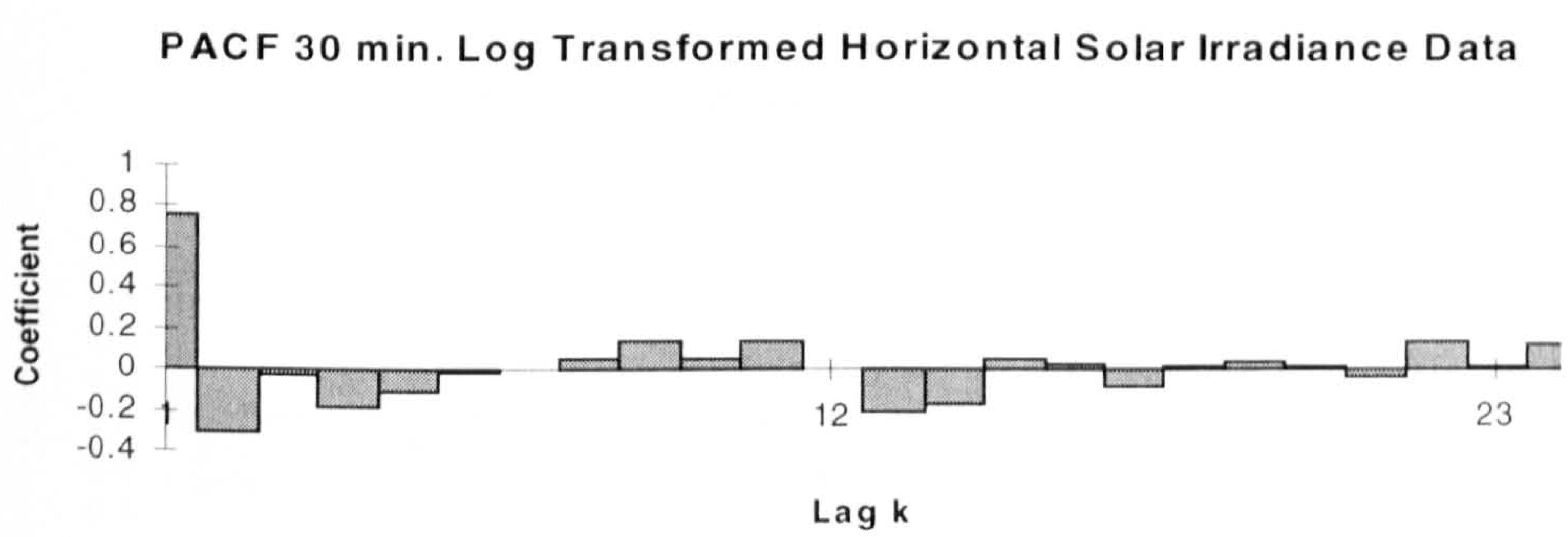
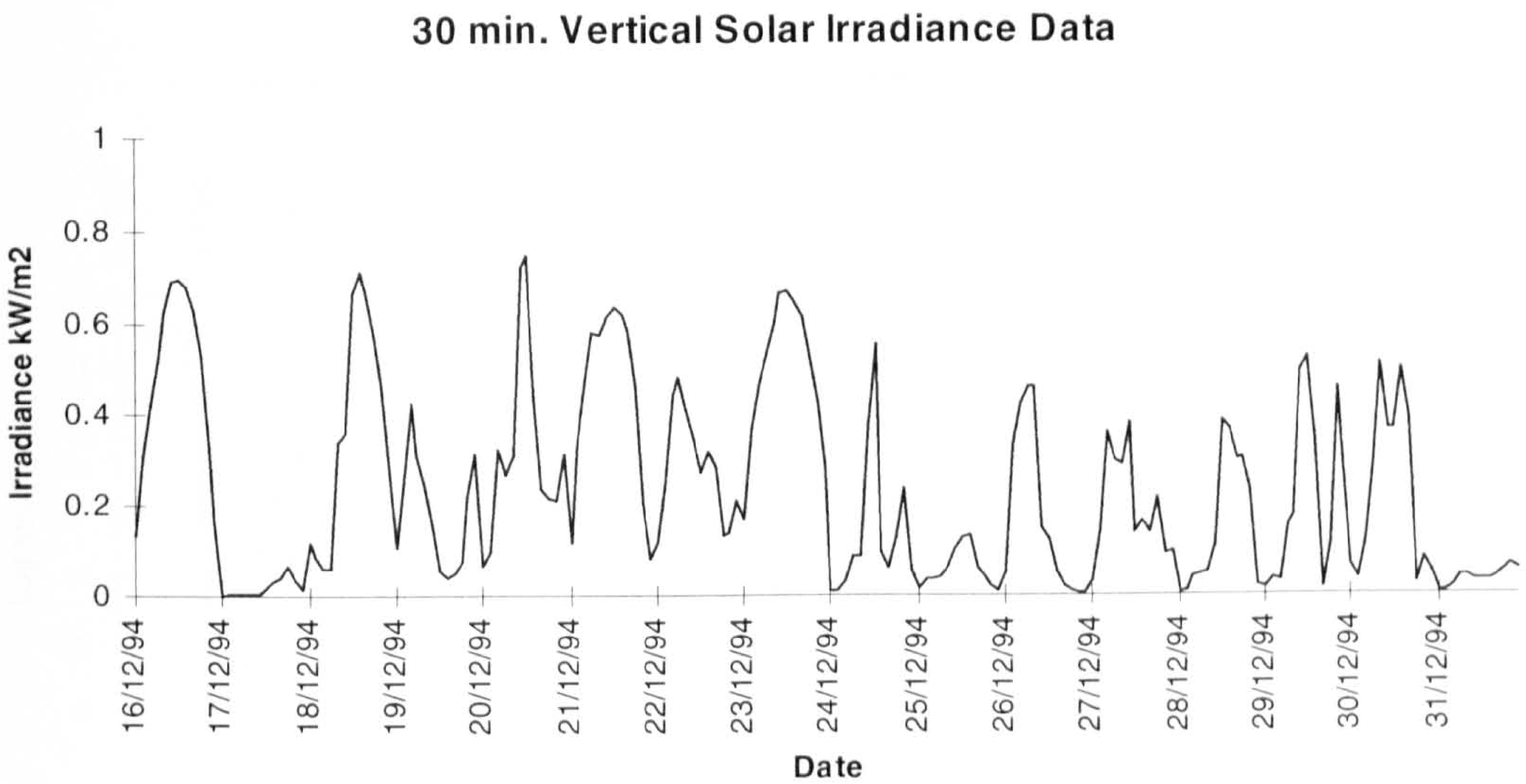
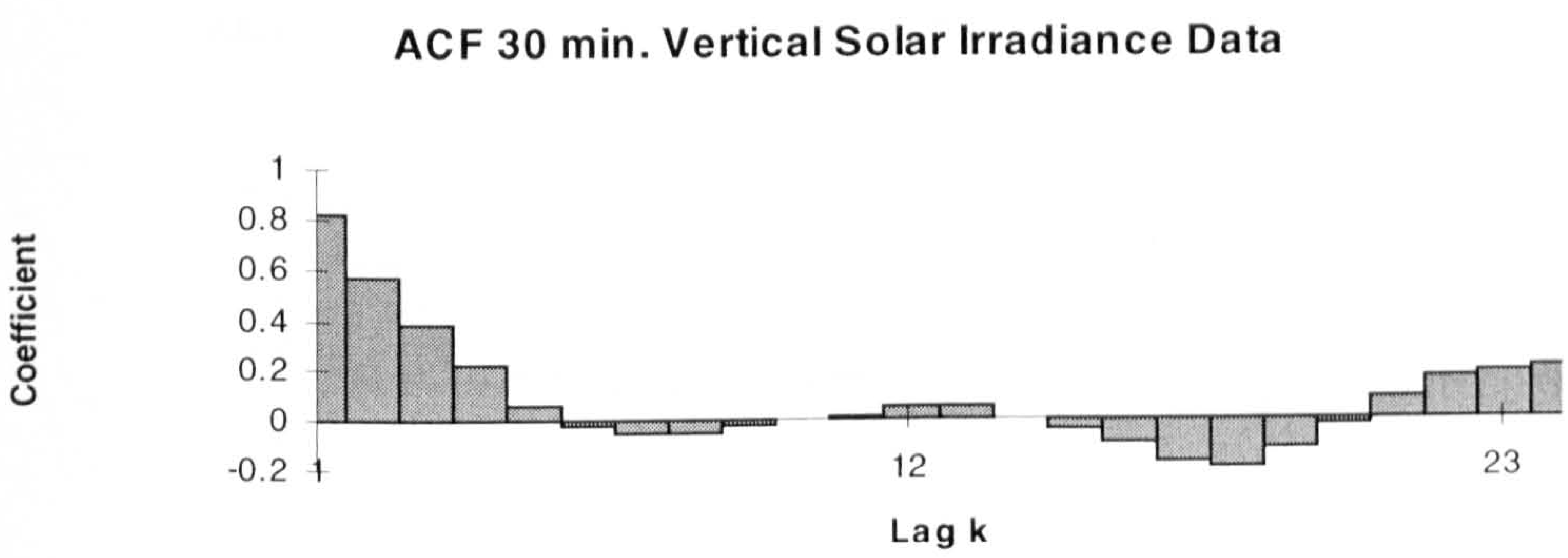


Figure 4.19.3 Vertical Solar Irradiance - 30 minute averages, DEC94_30

a)



b)



c)

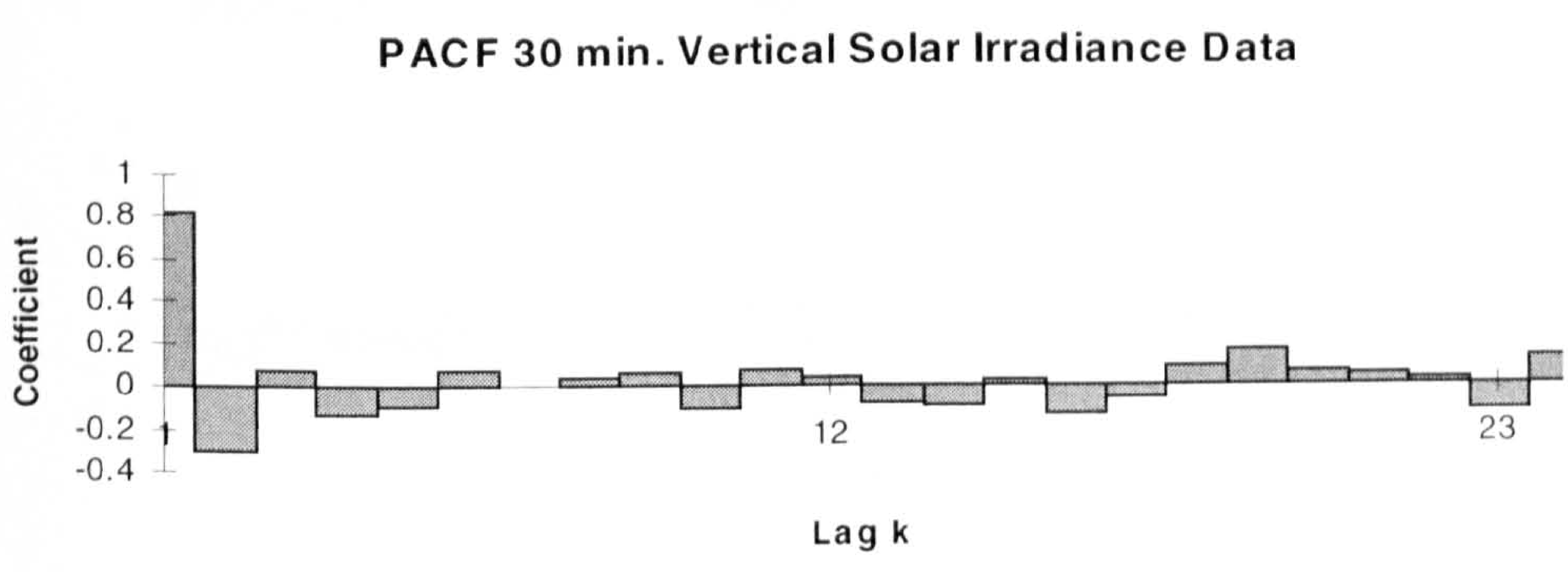
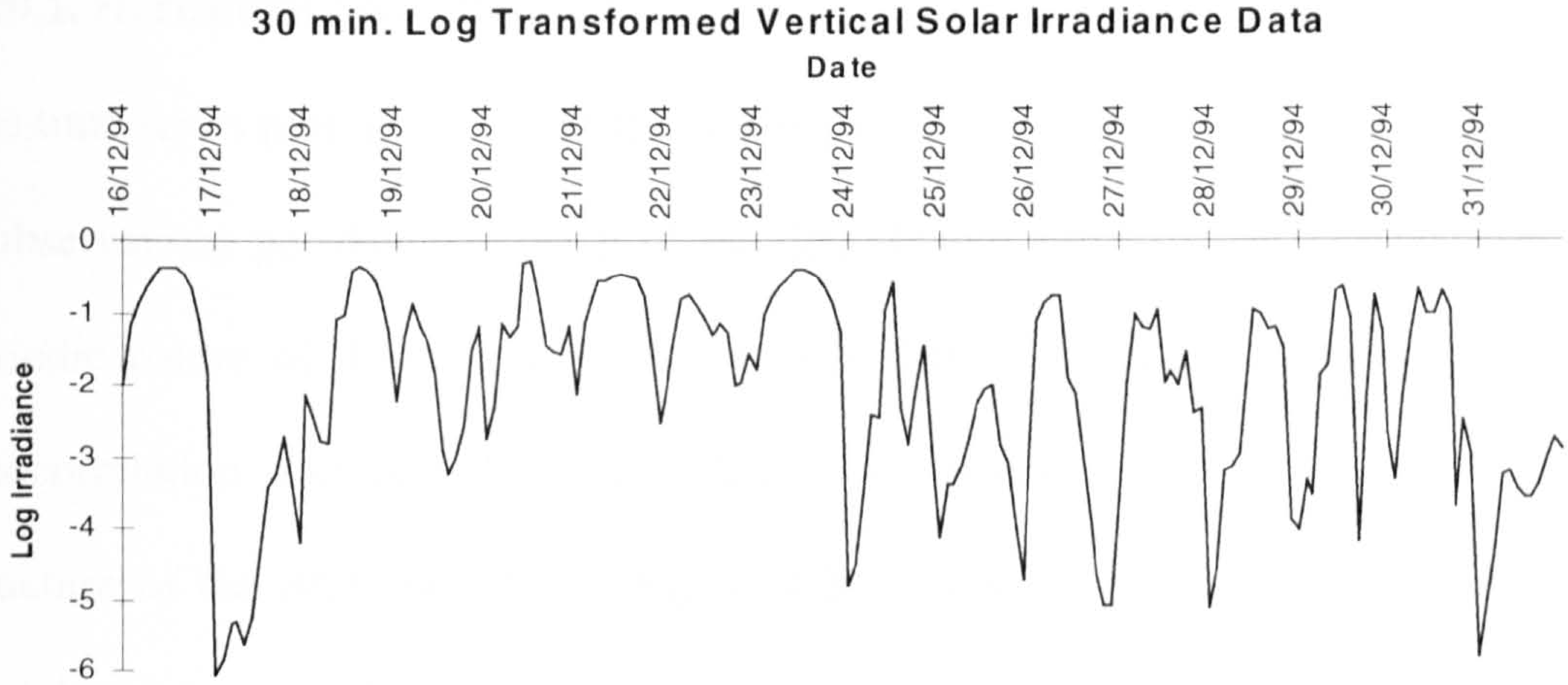
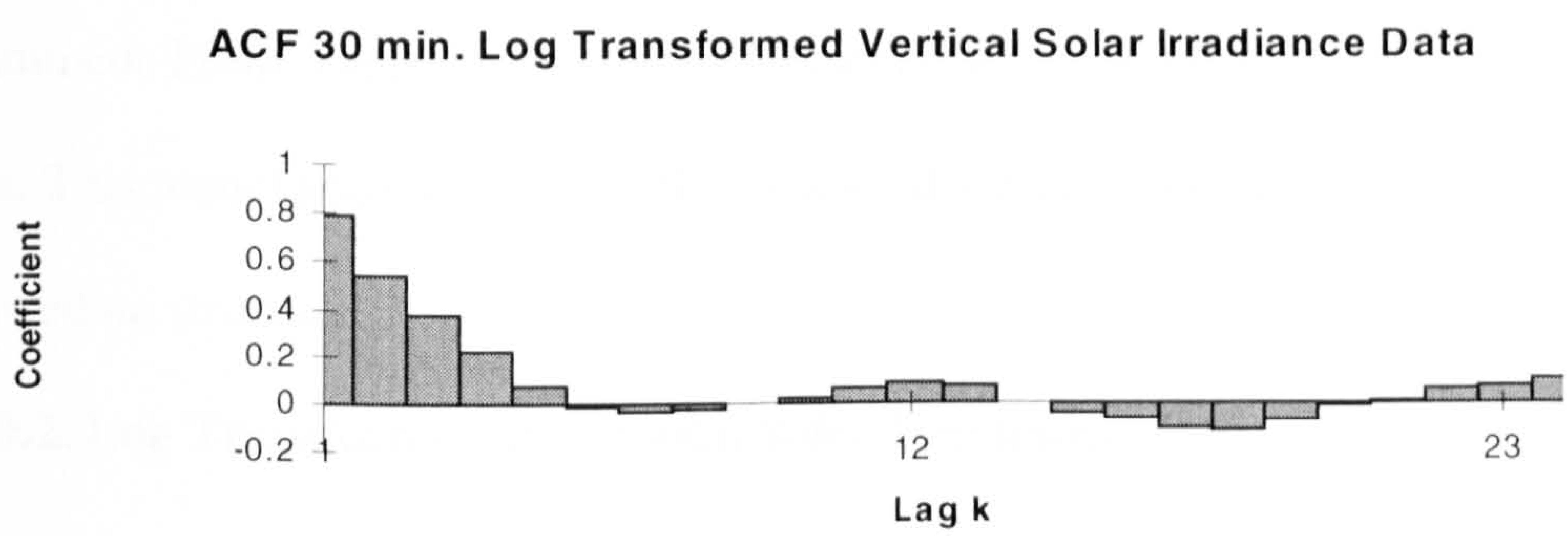


Figure 4.19.4 Log transformed Vertical Solar Irradiance - 30 minute averages, DEC94_30

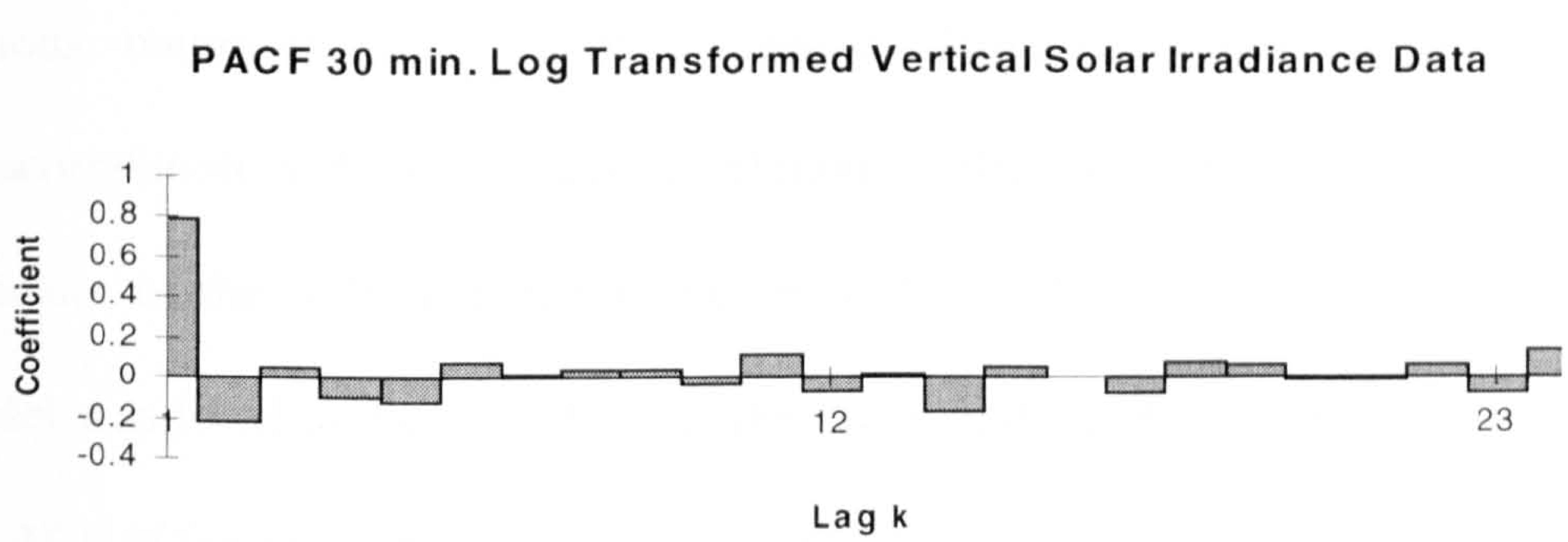
a)



b)



c)



4.20. December 1994 (16th - 31st) - Sixty minute averages

This data set, known as DEC94_60, contains 60 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 16th and 31st December 1994.

4.20.1. Horizontal Solar Irradiance

The time series plot, Figure 4.20.1(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.20.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.20.1(b), and the structure of the ACF and PACF, Figure 4.20.1(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 42% of the total variance but the ACF of the residuals had significant values at lag 1 and lag 2.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.20.1(b) an ARIMA(2,1,0)(1,0,0)6 model was fitted to the data. This model accounted for 40% of the total variance and the ACF of the residuals showed no structure.

4.20.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.20.2(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.20.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.20.2(b), and the structure of the ACF and PACF, Figure 4.20.2(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 40% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.20.2(b) an ARIMA(0,1,0)(1,0,0)6 model was fitted to the data. This model also accounted for 30% of the total variance and the ACF of the residuals showed no structure.

4.20.3. Vertical Solar Irradiance

The time series plot, Figure 4.20.3(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.20.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.20.3(b), and the structure of the ACF and PACF, Figure 4.20.3(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 43% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.20.3(b) an ARIMA(2,1,0)(1,0,0)6 model was fitted to the data. This model accounted for 36% of the total variance and the ACF of the residuals showed no structure.

4.20.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.20.4(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.20.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.20.4(b), and the structure of the ACF and PACF, Figure 4.20.4(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 36% of the total variance and the ACF of the showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.20.4(b) the ACF and PACF of the differenced series showed no structure and an ARIMA model could not be determined.

Table 4.20.1 Summary information for Horizontal Solar Irradiance - 60 minute averages (datafile DEC94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0793	0.0425	0.0046	0.1613

b)

$2/\sqrt{96} = 0.204$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.525	0.525	0.191	0.191
2	-0.111	-0.533	-0.371	-0.423
3	-0.394	-0.047	-0.499	-0.401
4	-0.208	0.133	-0.223	-0.320
6	0.347	0.020	0.444	0.083

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.5752	0.0849	6.77	0.09699	0.001043	42
	SAR6	0.4864	0.0927	5.25			
	CONST	0.0171	0.0033	5.17			
ARIMA(2,1,0)(1,0,0)6	AR1	0.1144	0.0968	1.18	0.10004	0.001087	40
	AR2	-0.4134	0.0948	-4.36			
	SAR6	0.4906	0.0953	5.15			

Table 4.20.2 Summary information for Log Transformed Horizontal Solar Irradiance - 60 minute averages (datafile DEC94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.7357	0.7297	-5.3890	-1.8247

b)

$2/\sqrt{96} = 0.204$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.511	0.511	-0.001	-0.001
2	0.034	-0.308	-0.194	-0.194
3	-0.255	-0.179	-0.361	-0.375
4	-0.191	0.097	-0.232	-0.358
6	0.284	0.084	0.426	0.178

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.6164	0.827	7.46	29.4711	0.3169	40
	SAR6	0.5165	0.969	5.33			
	CONST	-0.5056	0.0575	-8.79			
ARIMA(0,1,0)(1,0,0)6	SAR6	0.6014	0.0903	6.66	34.6642	0.3688	30

Table 4.20.3 Summary information for Vertical Solar Irradiance - 60 minute averages (datafile DEC94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2383	0.2035	0.0026	0.6910

b)

$2/\sqrt{96} = 0.204$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.653	0.653	0.090	0.090
2	0.245	-0.317	-0.228	-0.238
3	-0.007	-0.021	-0.303	-0.274
4	-0.051	0.081	-0.120	-0.148
6	0.046	0.053	0.166	0.024

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.6711	0.0775	8.67	2.18162	0.02346	43
	SAR6	0.1651	0.1031	1.60			
	CONST	0.0647	0.0156	4.14			
ARIMA(2,1,0)(1,0,0)6	AR1	0.0997	0.1012	0.99	2.43135	0.02643	36
	AR2	-0.2406	0.1012	-2.38			
	SAR6	0.1755	0.1028	1.71			

Table 4.20.4 Summary information for Log Transformed Vertical Solar Irradiance - 60 minute averages (datafile DEC94_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.0330	1.3510	-5.9520	-0.370

b)

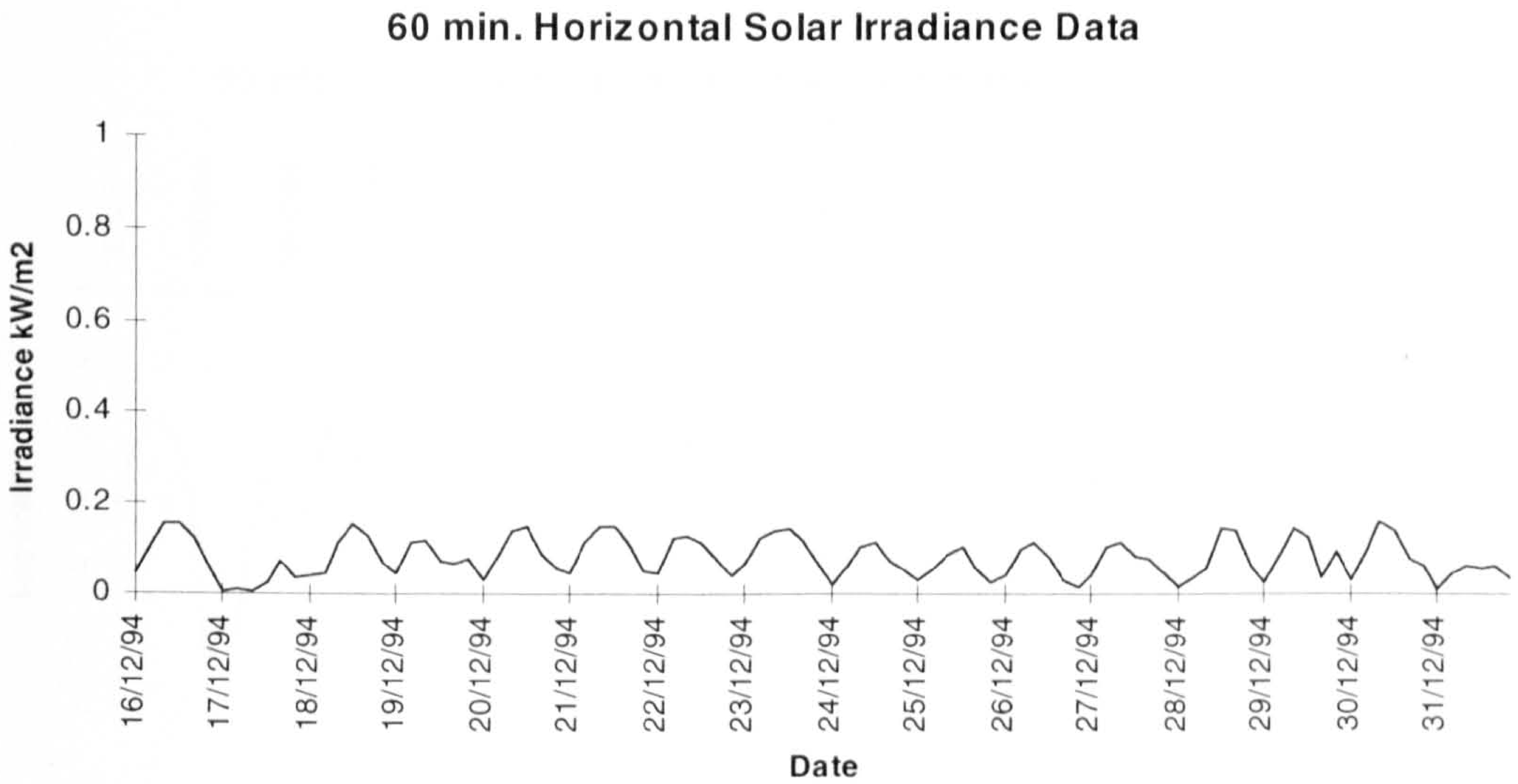
$2/\sqrt{96} = 0.204$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.595	0.595	-0.066	-0.066
2	0.238	-0.179	-0.147	-0.152
3	-0.003	-0.102	-0.257	-0.286
4	-0.037	0.083	-0.094	-0.189
6	0.065	0.044	0.176	0.014

c)

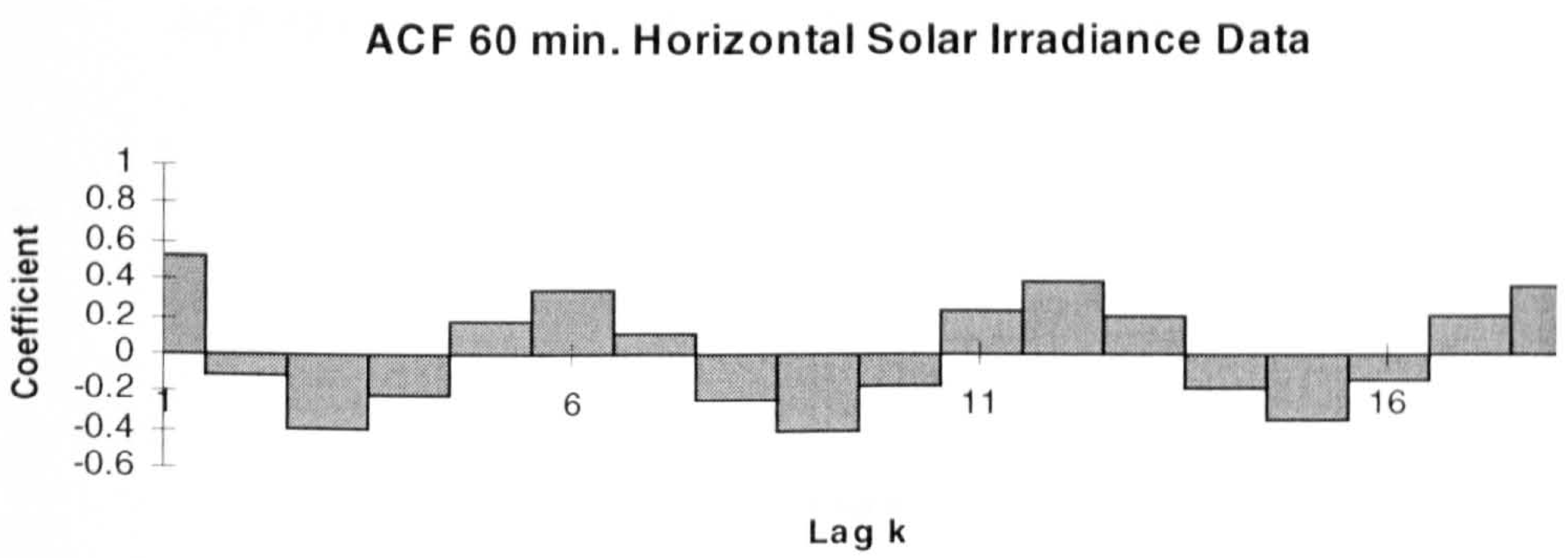
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.6154	0.0821	7.50	108.260	1.164	36
	SAR6	0.1807	0.1066	1.69			
	CONST	-0.6387	0.1102	-5.79			

Figure 4.20.1 Horizontal Solar Irradiance - 60 minute averages, DEC94_60

a)



b)



c)

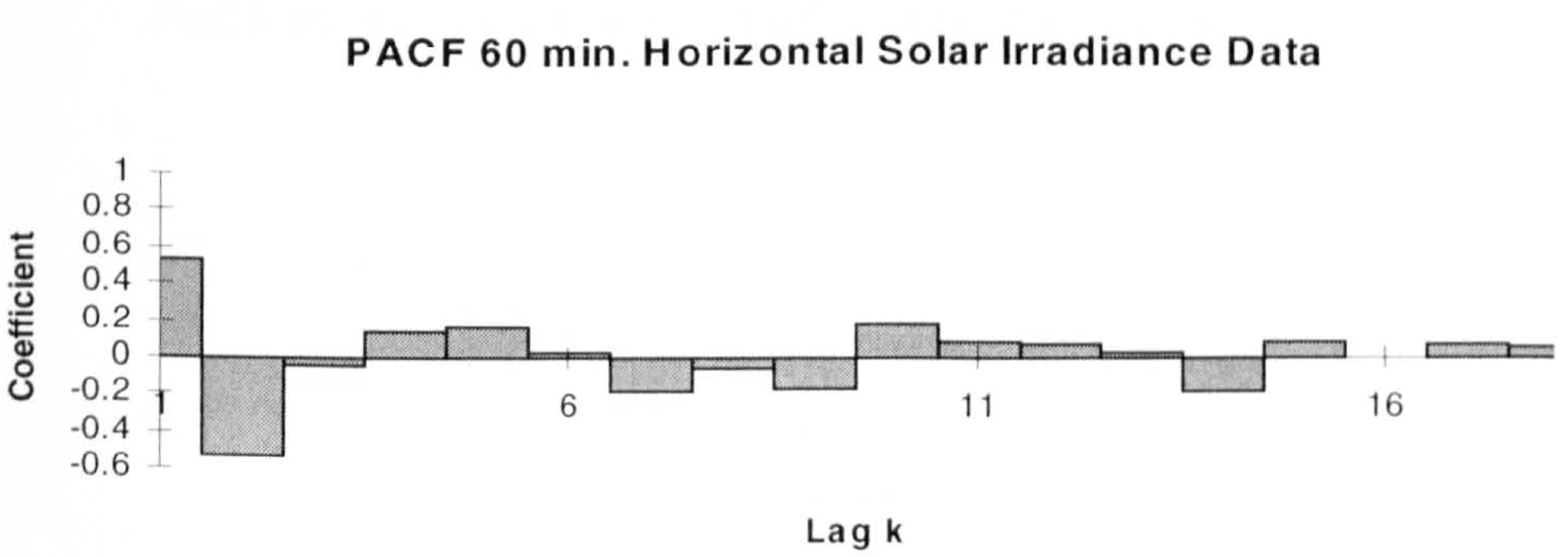
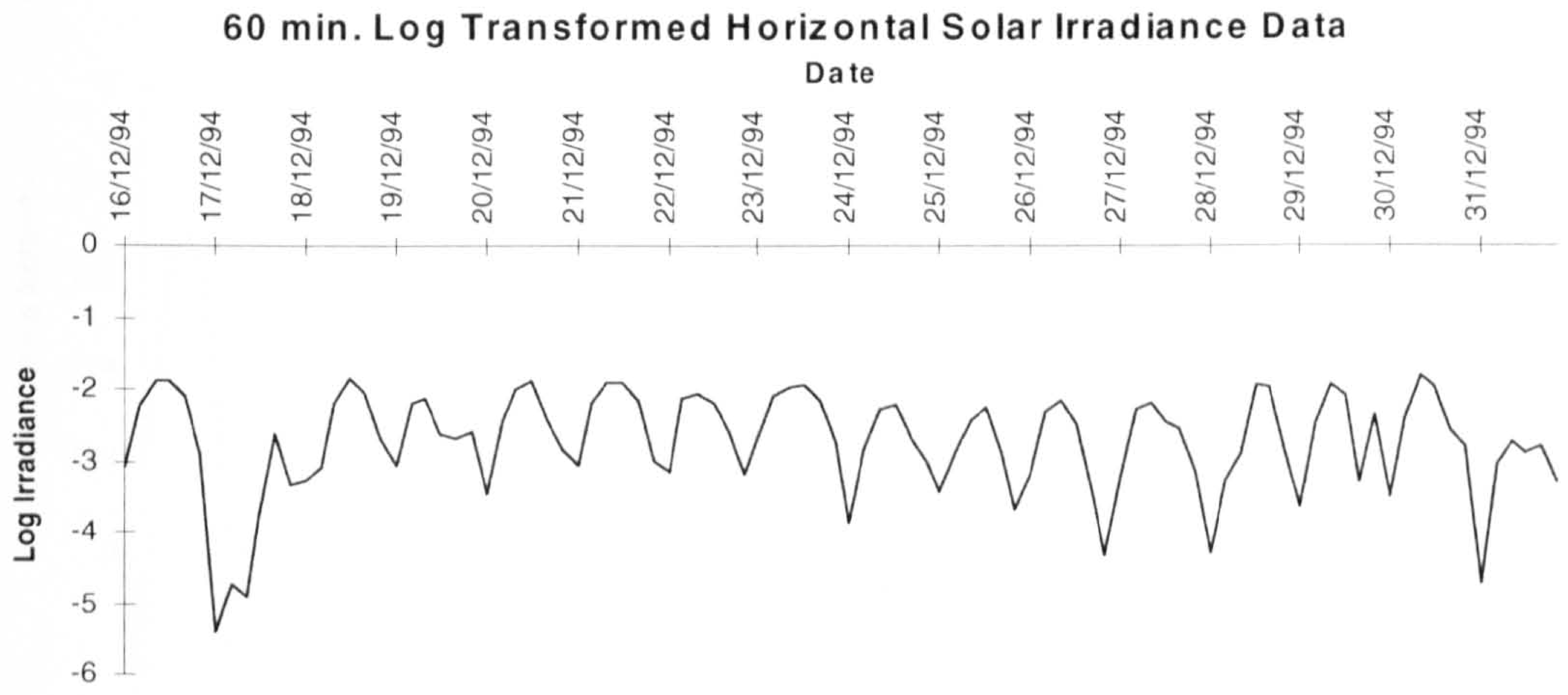
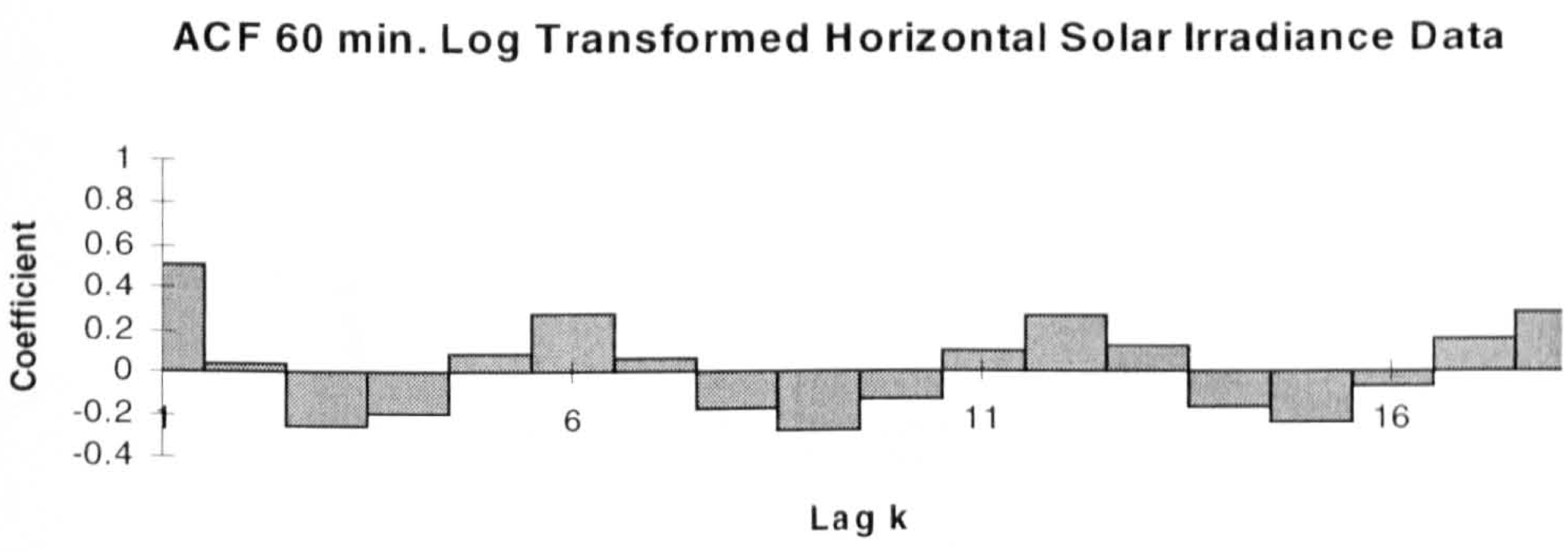


Figure 4.20.2 Log transformed Horizontal Solar Irradiance - 60 minute averages, DEC94_60

a)



b)



c)

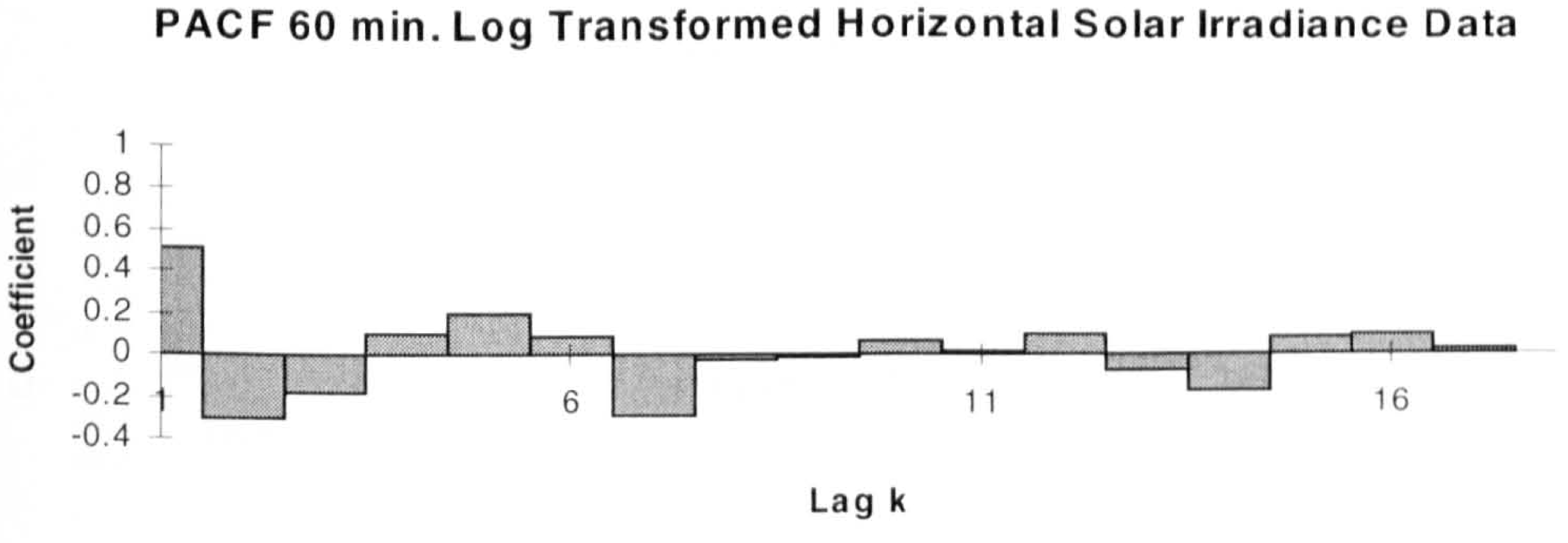
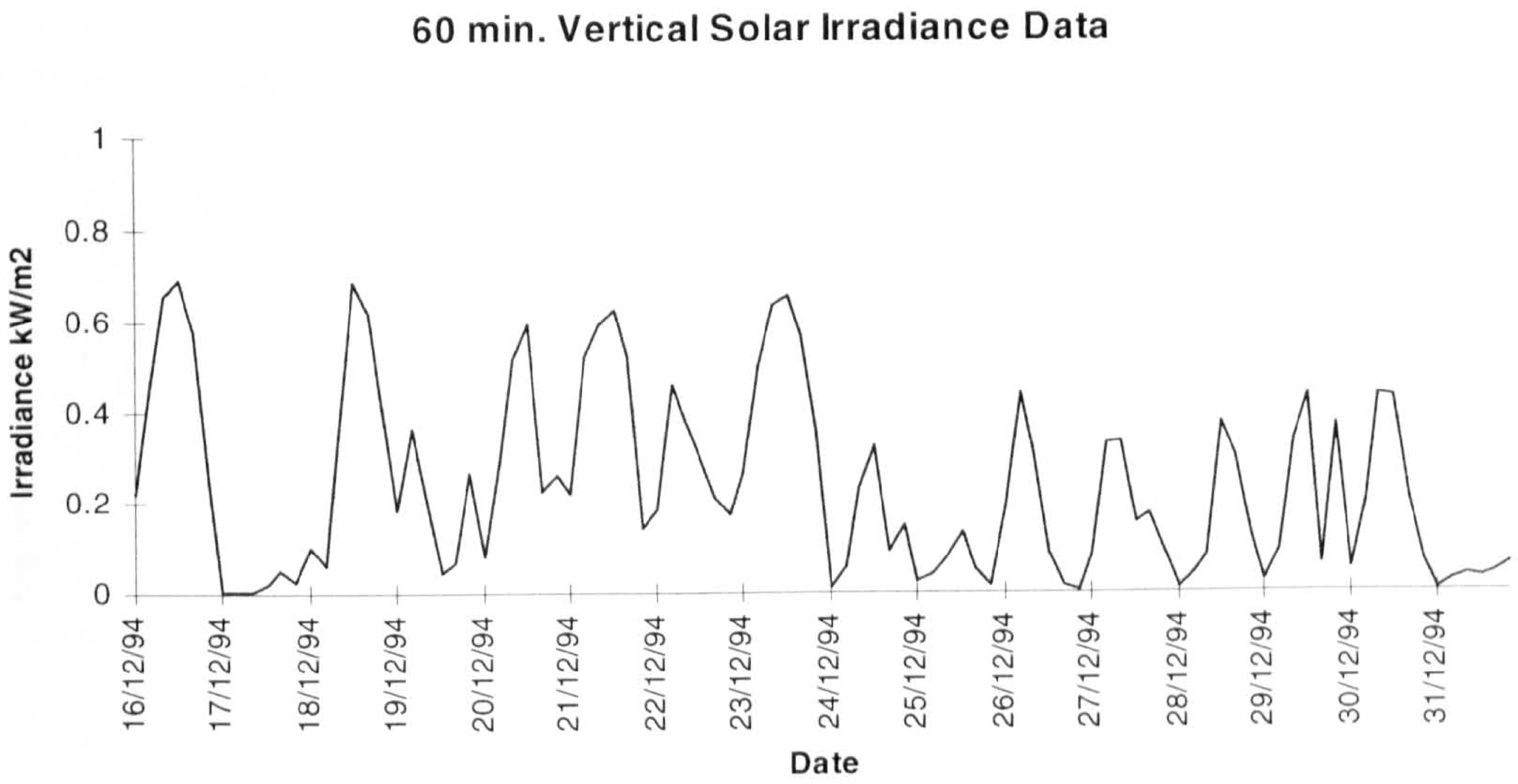
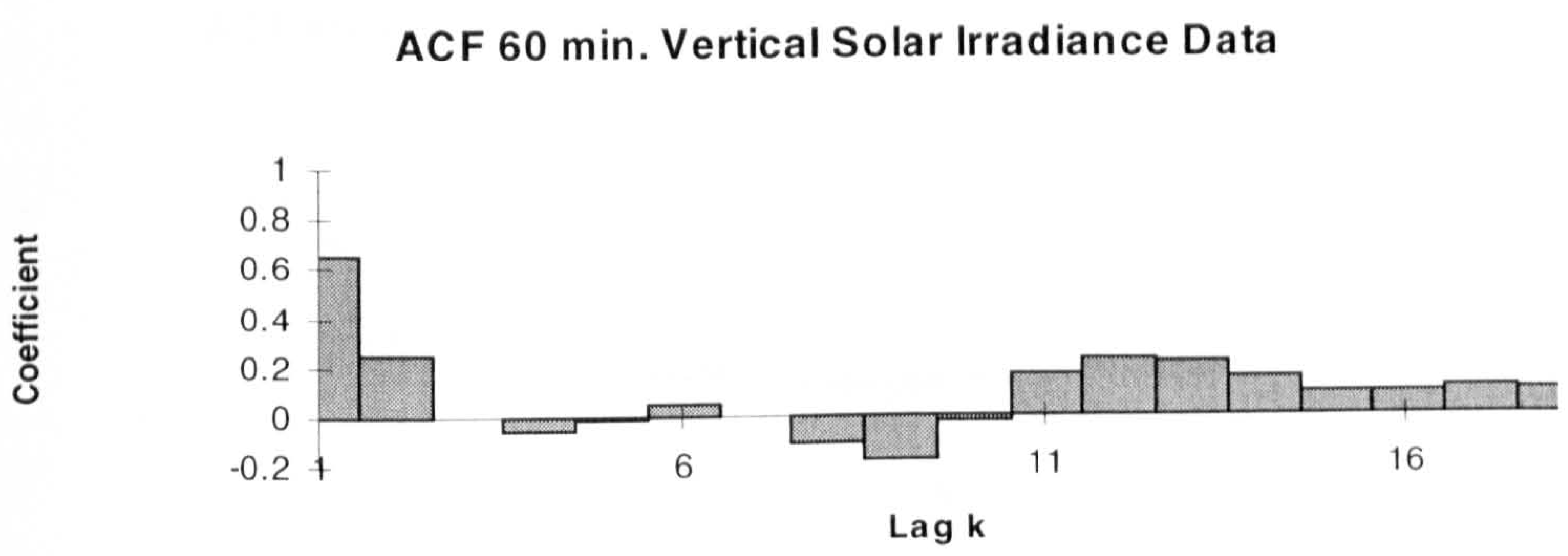


Figure 4.20.3 Vertical Solar Irradiance - 60 minute averages, DEC94_60

a)



b)



c)

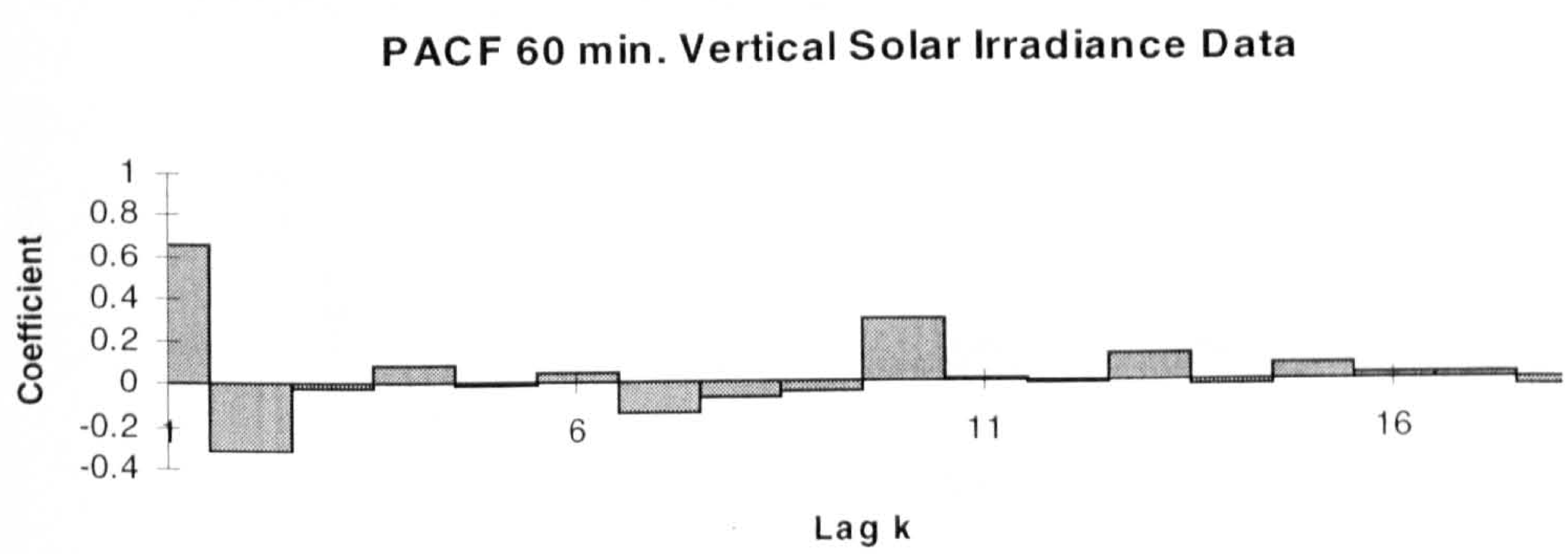
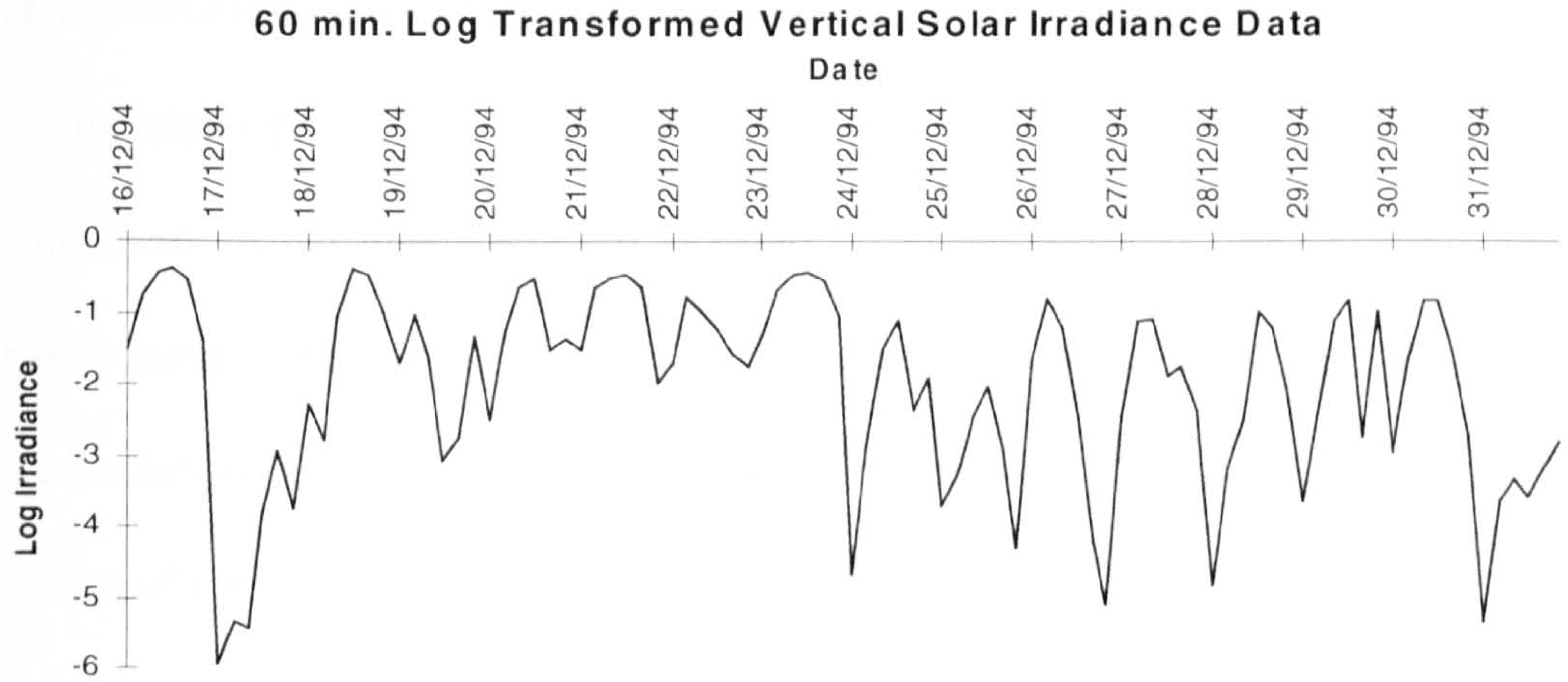
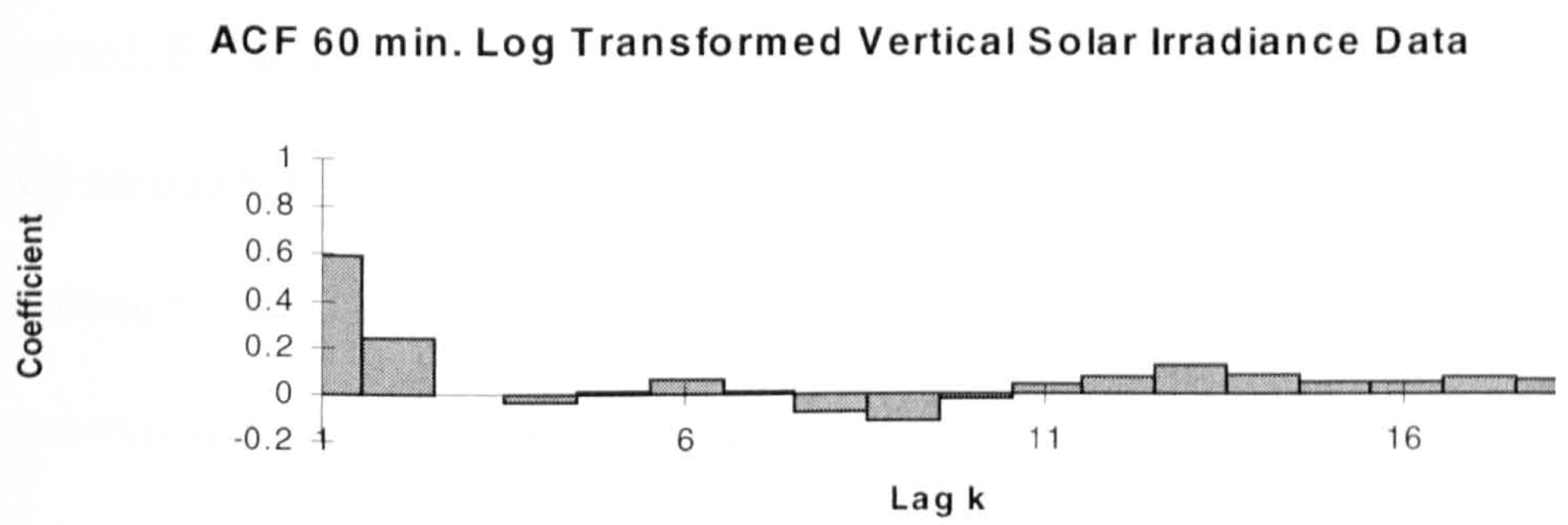


Figure 4.20.4 Log transformed Vertical Solar Irradiance - 60 minute averages, DEC94_60

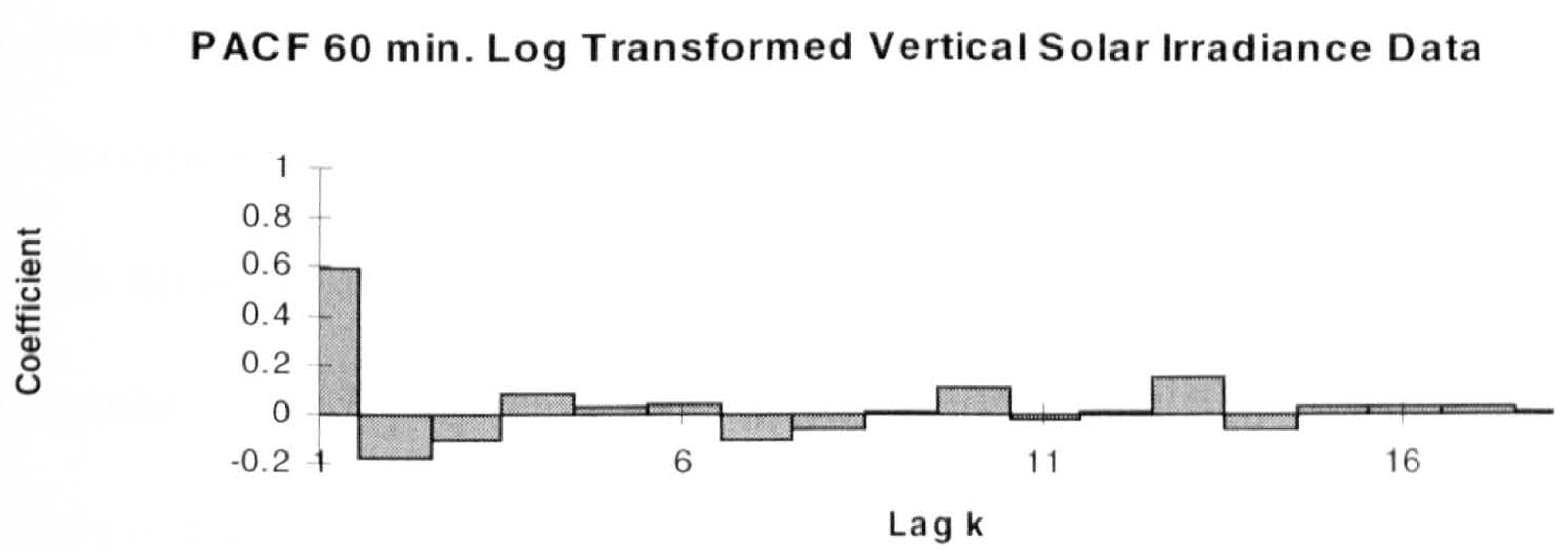
a)



b)



c)



4.21. June 1995 (1st - 13th) - Ten minute averages

This data set, known as JUN95_10, contains 10 minute averaged Horizontal and Vertical Solar Irradiance data recorded between 1st and 13th June 1995.

4.21.1. Horizontal Solar Irradiance

The time series plot, Figure 4.21.1(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.21.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.21.1(b), and the structure of the ACF and PACF, Figure 4.21.1(b) & (c), an ARIMA(4,0,0) model was fitted to the data. This model accounted for 72% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.21.1(b) an ARIMA(4,1,0) model was fitted to the data. This model accounted for 71% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was also included in the above models, but there was no significant improvement in either model.

4.21.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.21.2(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.21.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.21.2(b), and the structure of the ACF and PACF, Figure 4.21.2(b) & (c), an ARIMA(3,0,0) model was

fitted to the data. This model accounted for 81% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.21.2(b) an ARIMA(3,1,0) model was fitted to the data. However, the backforecasts did not die out rapidly and this model was rejected. An ARIMA(4,1,0) model was then fitted to the data, accounted for 80% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the above models but there was no significant improvement in either model.

4.21.3. Vertical Solar Irradiance

The time series plot, Figure 4.21.3(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.21.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.21.3(b), and the structure of the ACF and PACF, Figure 4.21.3(b) & (c), an ARIMA(4,0,0) model was fitted to the data. This model accounted for 73% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.21.3(b) an ARIMA(4,1,0) model was fitted to the data. This model accounted for 72% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the above models but there was no significant improvement in either model.

4.21.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.21.4(a), displays the daily cyclic nature of the data with 84 observations per day. The ACF of the data, Figure 4.21.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 84. From the autocorrelation and partial autocorrelation coefficients, Table 4.21.4(b), and the structure of the ACF and PACF, Figure 4.21.4(b) & (c), an ARIMA(3,0,0) model was fitted to the data. However, the backforecasts did not die out rapidly and this model was rejected.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.21.4(b) ARIMA(2,1,0) model was fitted to the data. This model accounted for 84% of the total variance but the ACF of the residuals had significant values at lag 3 and lag 4. An ARIMA(4,1,0) model was fitted to the data, this model accounted for 84% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the above models but there was no significant improvement in either model.

Table 4.21.1 Summary information for Horizontal Solar Irradiance - 10 minute averages (datafile JUN95_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2274	0.1683	0.0137	0.9127

b)

$2/\sqrt{1092} = 0.06$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.837	0.837	-0.173	-0.173
2	0.730	0.099	-0.205	-0.242
3	0.690	0.190	-0.074	-0.175
4	0.674	0.139	0.016	-0.102
84	0.283	0.048	0.017	-0.024

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(4,0,0)	AR1	0.7086	0.0300	23.59	8.62766	0.00793	72
	AR2	-0.0382	0.0368	-1.04			
	AR3	0.0888	0.0368	2.41			
	AR4	0.1402	0.0300	4.67			
	CONST	0.0225	0.0027	8.36			
ARIMA(4,1,0)	AR1	-0.2751	0.0302	-9.12	8.79387	0.00809	71
	AR2	-0.3082	0.0307	-10.04			
	AR3	-0.2013	0.0307	-6.56			
	AR4	-0.1025	0.0302	-3.40			
ARIMA(4,0,0)(1,0,0)84	AR1	0.7074	0.0301	23.54	8.61318	0.00793	72
	AR2	-0.0389	0.0368	-1.06			
	AR3	0.0896	0.0369	2.43			
	AR4	0.1391	0.0301	4.63			
	SAR84	0.0355	0.0309	1.15			
	CONST	0.02226	0.00270	8.26			
ARIMA(4,1,0)(1,0,0)84	AR1	-0.2752	0.0302	-9.12	8.79059	0.00809	71
	AR2	-0.0308	0.0307	-10.04			
	AR3	-0.2010	0.0308	-6.53			
	AR4	-0.1022	0.0302	-3.38			
	SAR84	0.0196	0.0309	0.63			

Table 4.21.2 Summary information for Log Transformed Horizontal Solar Irradiance - 10 minute averages (datafile JUN95_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.7748	0.8144	-4.2904	-0.0913

b)

$2/\sqrt{1092} = 0.06$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.898	0.898	-0.051	-0.051
2	0.807	0.002	-0.181	-0.174
3	0.750	0.132	-0.067	-0.089
4	0.708	0.056	-0.057	-0.102
84	0.424	-0.026	0.007	0.013

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1	0.8990	0.0301	29.92	136.193	0.125	81
	AR2	-0.1185	0.0404	-2.93			
	AR3	0.1330	0.0300	4.43			
	CONST	-0.1549	0.0107	-14.46			
ARIMA(4,1,0)	AR1	-0.0851	0.0302	-2.82	138.673	0.128	80
	AR2	-0.1982	0.0301	-6.57			
	AR3	-0.0972	0.0301	-3.23			
	AR4	-0.1022	0.0302	-3.39			
ARIMA(3,1,0)(1,0,0)84	AR1						
	AR2						
	AR3						
	SAR84						
ARIMA(4,1,0)(1,0,0)84	AR1	-0.0866	0.0302	-2.86	138.605	0.128	81
	AR2	-0.1995	0.0302	-6.60			
	AR3	-0.0978	0.0302	-3.24			
	AR4	-0.1026	0.0302	-3.40			
	SAR84	0.0225	0.0309	0.73			

Table 4.21.3 Summary information for Vertical Solar Irradiance - 10 minute averages (datafile JUN95_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1172	0.1047	0.0074	0.6359

b)

$2/\sqrt{1092} = 0.06$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.841	0.841	-0.192	-0.192
2	0.743	0.122	-0.195	-0.240
3	0.707	0.192	-0.073	-0.183
4	0.694	0.149	0.041	-0.080
84	0.265	0.076	0.036	-0.025

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(4,0,0)	AR1	0.6859	0.0300	22.87	3.2307	0.00297	73
	AR2	-0.0169	0.0364	-0.46			
	AR3	0.0860	0.0364	2.36			
	AR4	0.1507	0.0300	5.02			
	CONST	0.01084	0.00165	6.57			
ARIMA(4,1,0)	AR1	-0.2972	0.0302	-9.83	3.29955	0.00304	72
	AR2	-0.3069	0.0309	-9.92			
	AR3	-0.2055	0.0309	-6.64			
	AR4	-0.0804	0.0302	-2.66			
ARIMA(4,0,0)(1,0,0)84	AR1	0.6858	0.0300	22.85	3.22194	0.00297	73
	AR2	-0.0188	0.0364	-0.52			
	AR3	0.0909	0.0364	2.49			
	AR4	0.1437	0.0300	4.78			
	SAR84	0.0619	0.0310	1.99			
	CONST	0.01071	0.00165	6.49			
ARIMA(4,1,0)(1,0,0)84	AR1	-0.2972	0.0303	-9.82	3.29487	0.00303	72
	AR2	-0.3076	0.0309	-9.94			
	AR3	-0.2045	0.0310	-6.60			
	AR4	-0.081	0.0303	-2.65			
	SAR84	0.0385	0.0311	1.24			

Table 4.21.4 Summary information for Log Transformed Vertical Solar Irradiance - 10 minute averages (datafile JUN95_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.4975	0.8643	-4.9063	-0.4527

b)

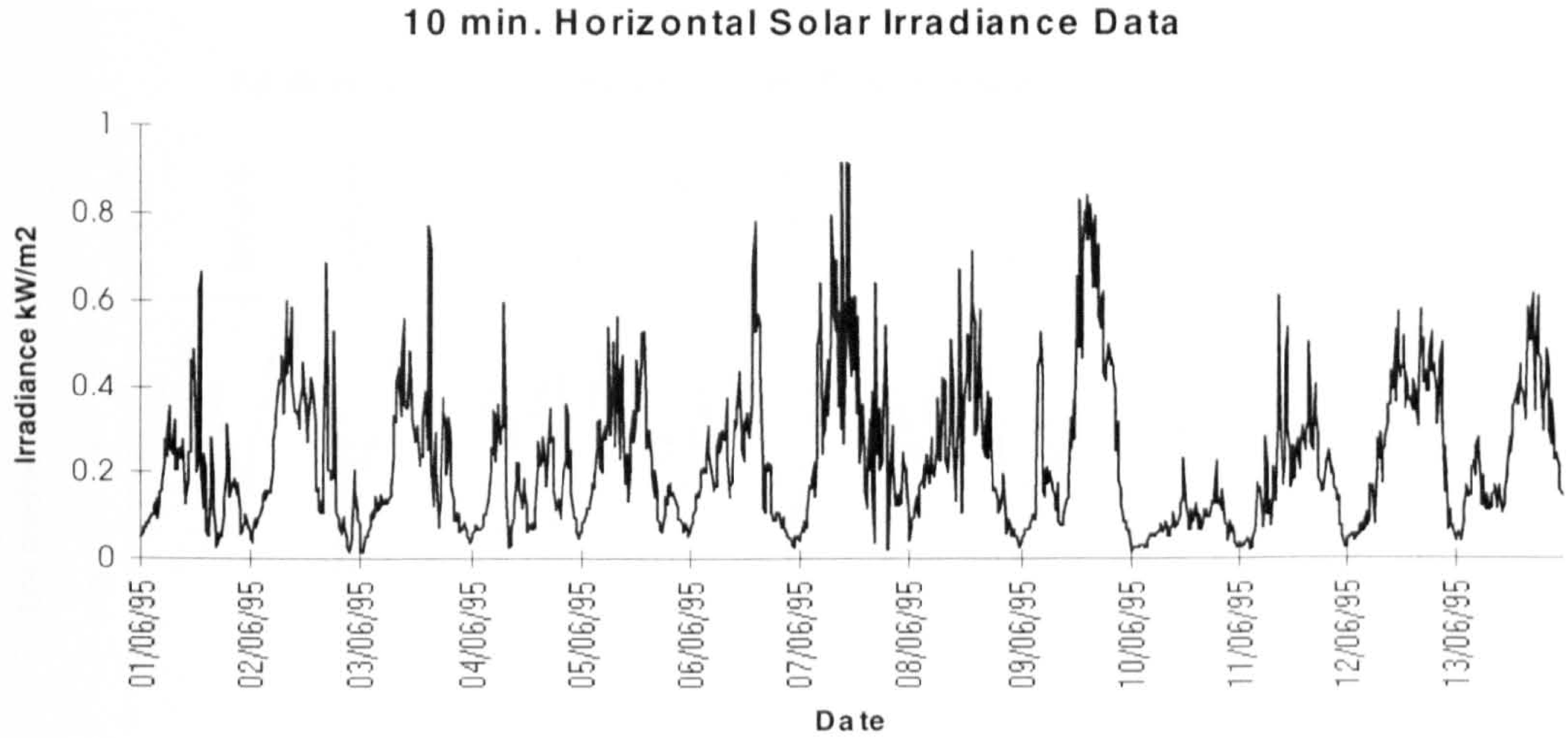
$2/\sqrt{1092} = 0.06$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.915	0.915	-0.024	-0.024
2	0.833	-0.018	-0.182	-0.183
3	0.783	0.146	-0.057	-0.068
4	0.743	0.039	0.035	-0.075
84	0.449	-0.028	0.012	0.009

c)

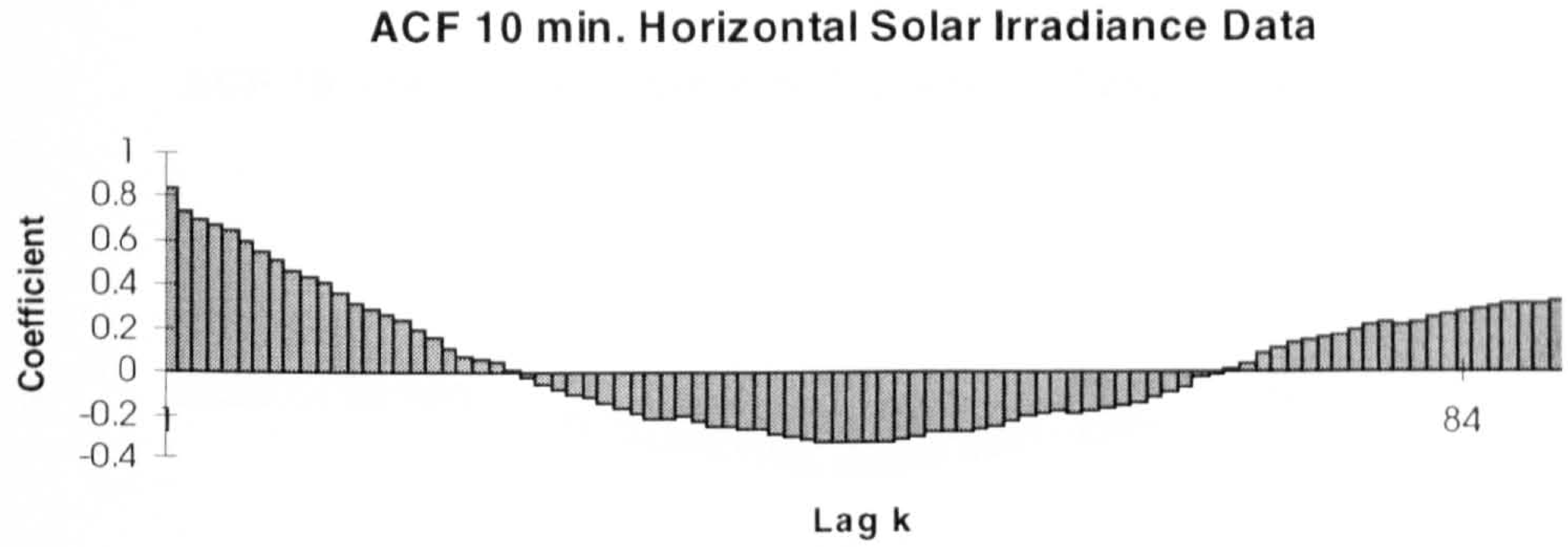
model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(3,0,0)	AR1						
	AR2						
	AR3						
	CONST						
ARIMA(4,1,0)	AR1	-0.0462	0.0302	-1.53	131.612	0.121	84
	AR2	-0.1990	0.0302	-6.59			
	AR3	-0.0717	0.0302	-2.37			
	AR4	-0.0755	0.0302	-2.50			
ARIMA(3,0,0)(1,0,0)84	AR1	0.9278	0.0301	30.83	128.737	0.118	84
	AR2	-0.1505	0.0409	-3.68			
	AR3	0.1466	0.0300	4.89			
	SAR84	0.0443	0.0310	1.43			
	CONST	-0.1824	0.0104	-17.51			
ARIMA(4,1,0)(1,0,0)84	AR1	-0.0485	0.0303	-1.60	131.536	0.121	83
	AR2	-0.2000	0.0302	-6061			
	AR3	-0.0727	0.0302	-2.41			
	AR4	-0.0761	0.0302	-2.51			
	SAR84	0.0244	0.0303	0.79			

Figure 4.21.1 Horizontal Solar Irradiance - 10 minute averages, JUN95_10

a)



b)



c)

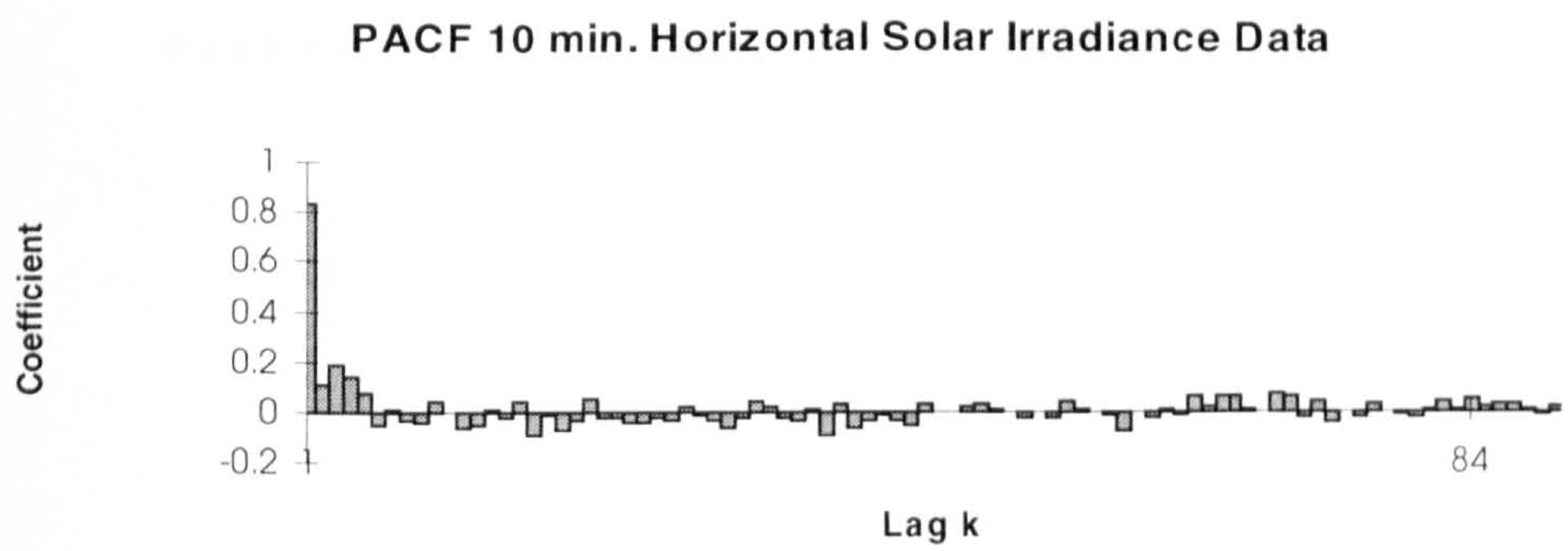
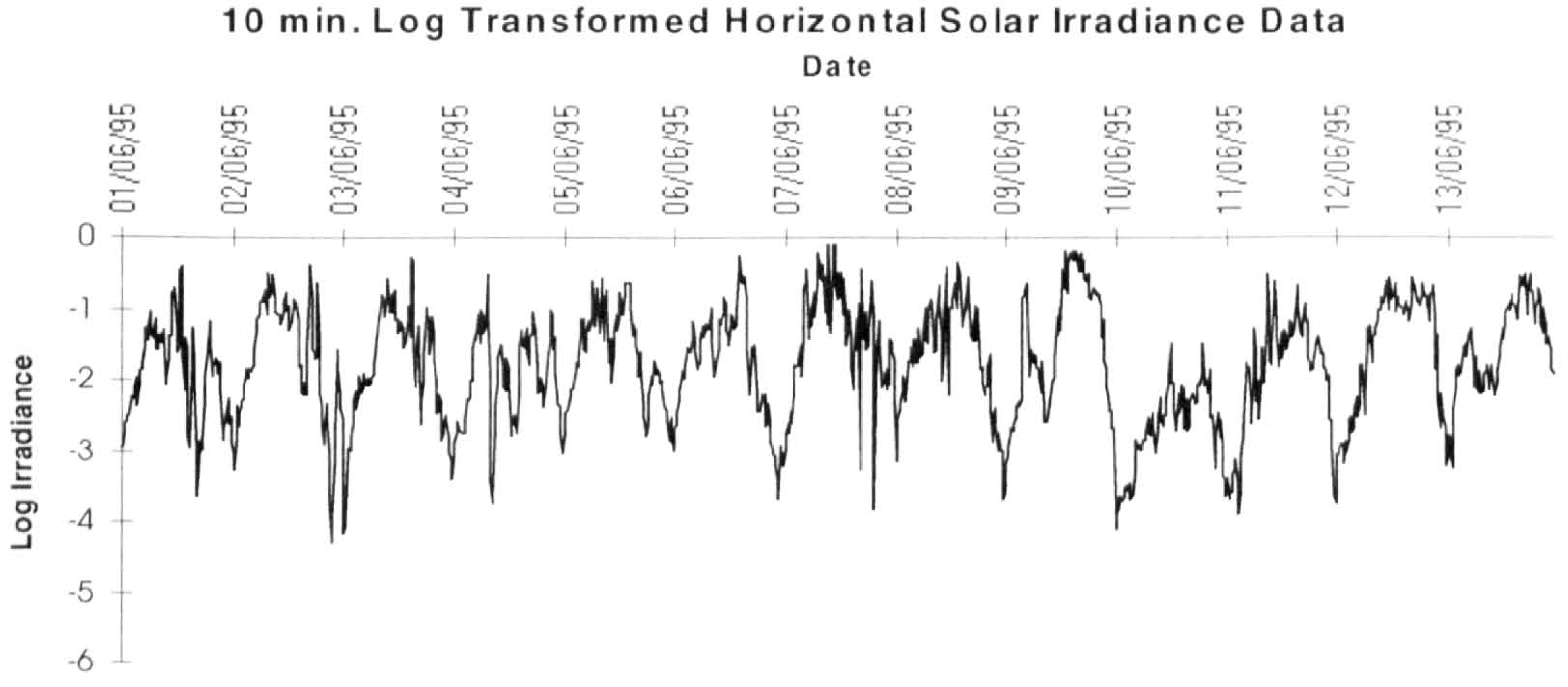
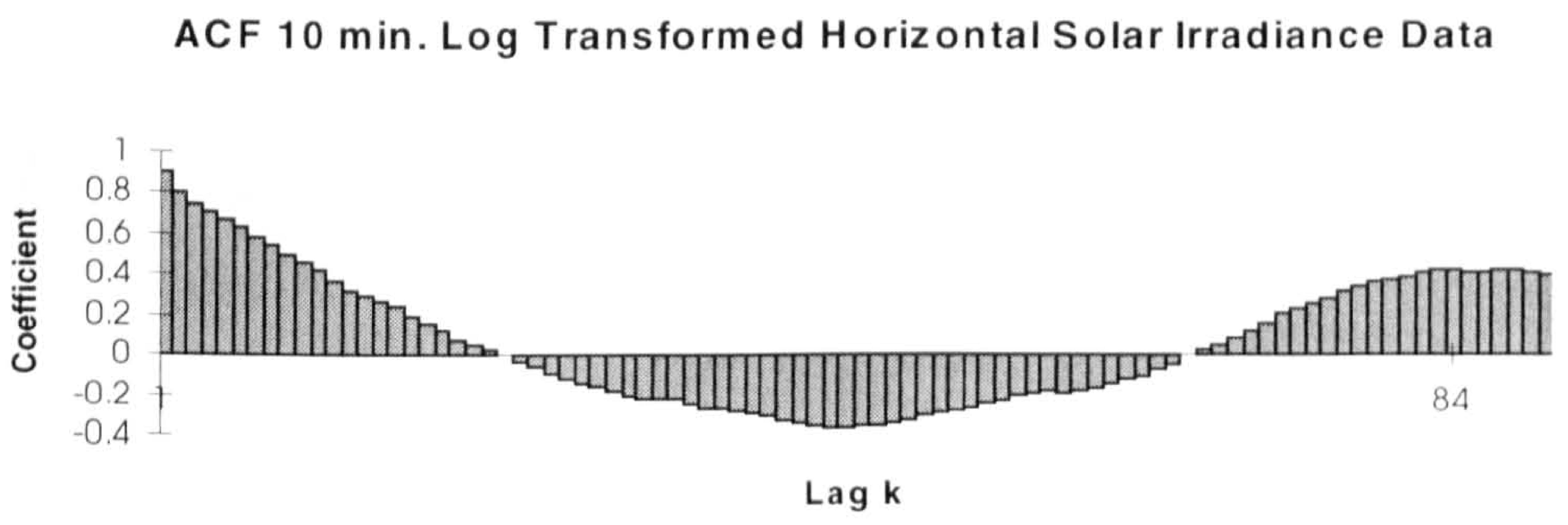


Figure 4.21.2 Log transformed Horizontal Solar Irradiance - 10 minute averages, JUN95_10

a)



b)



c)

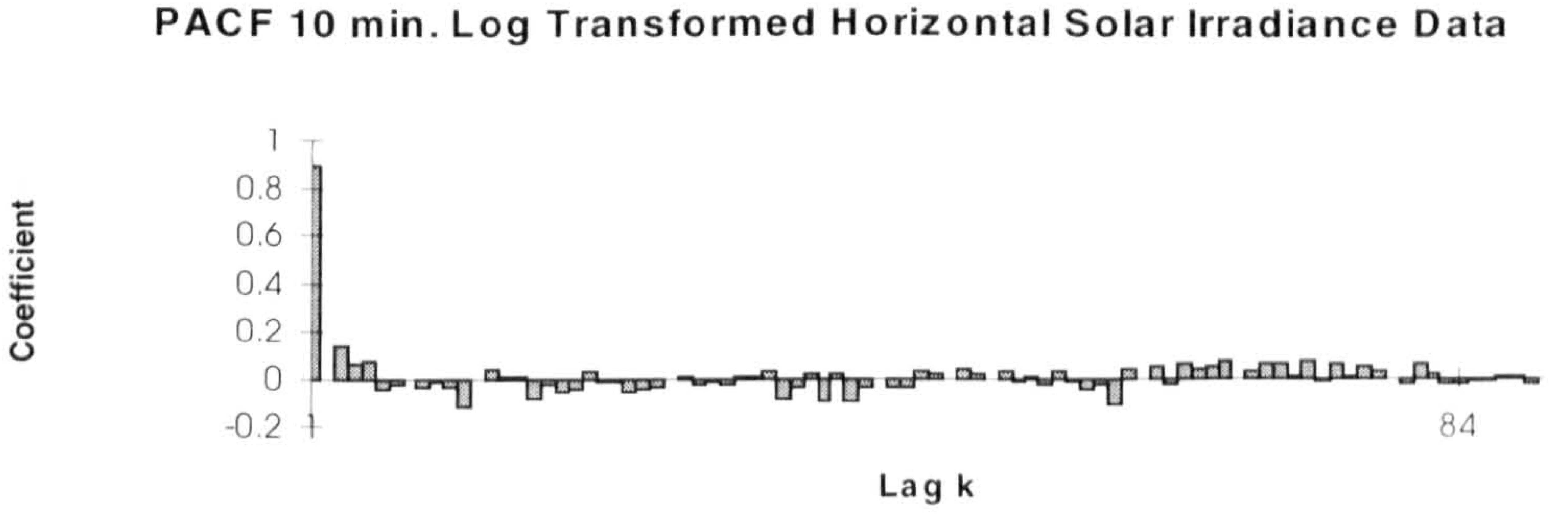
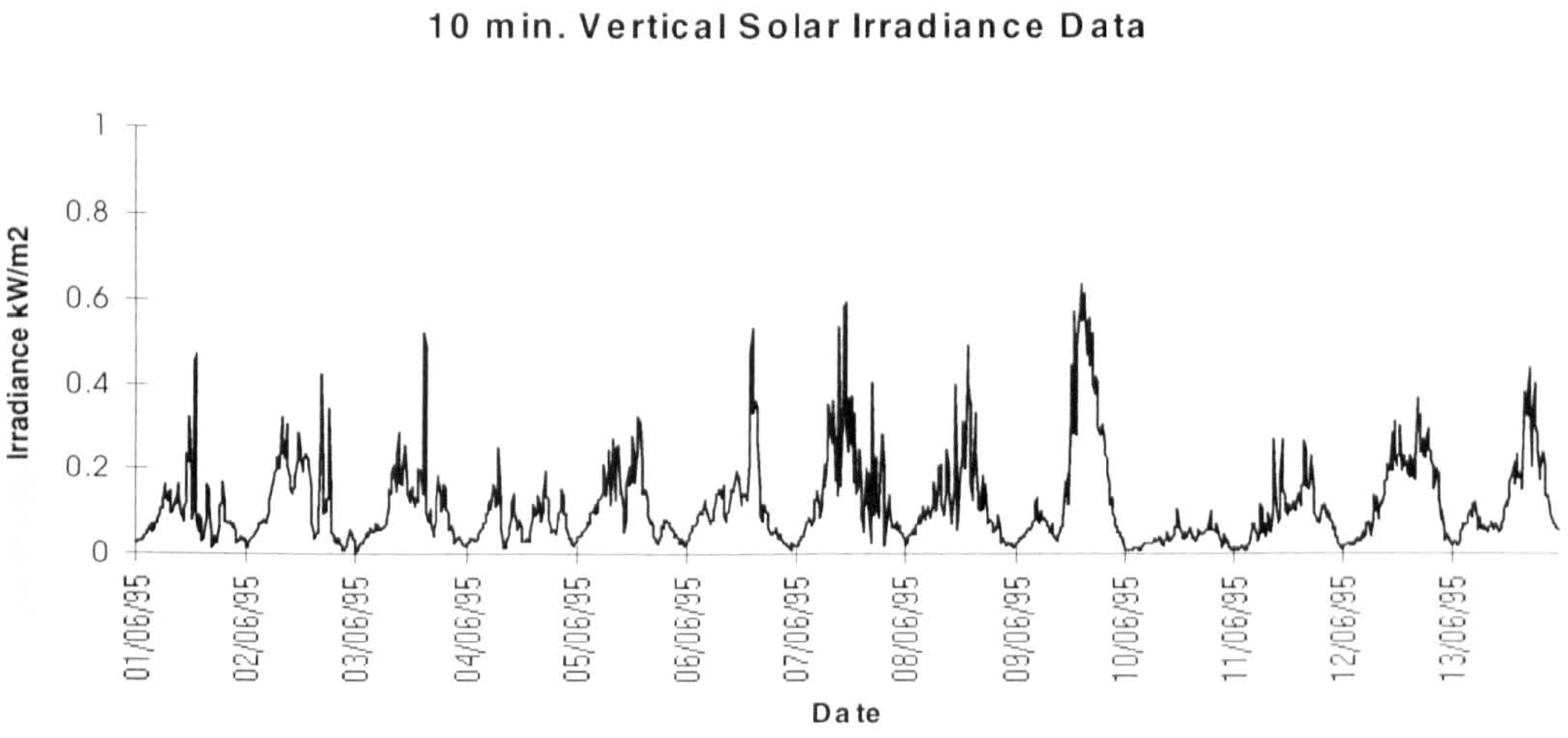
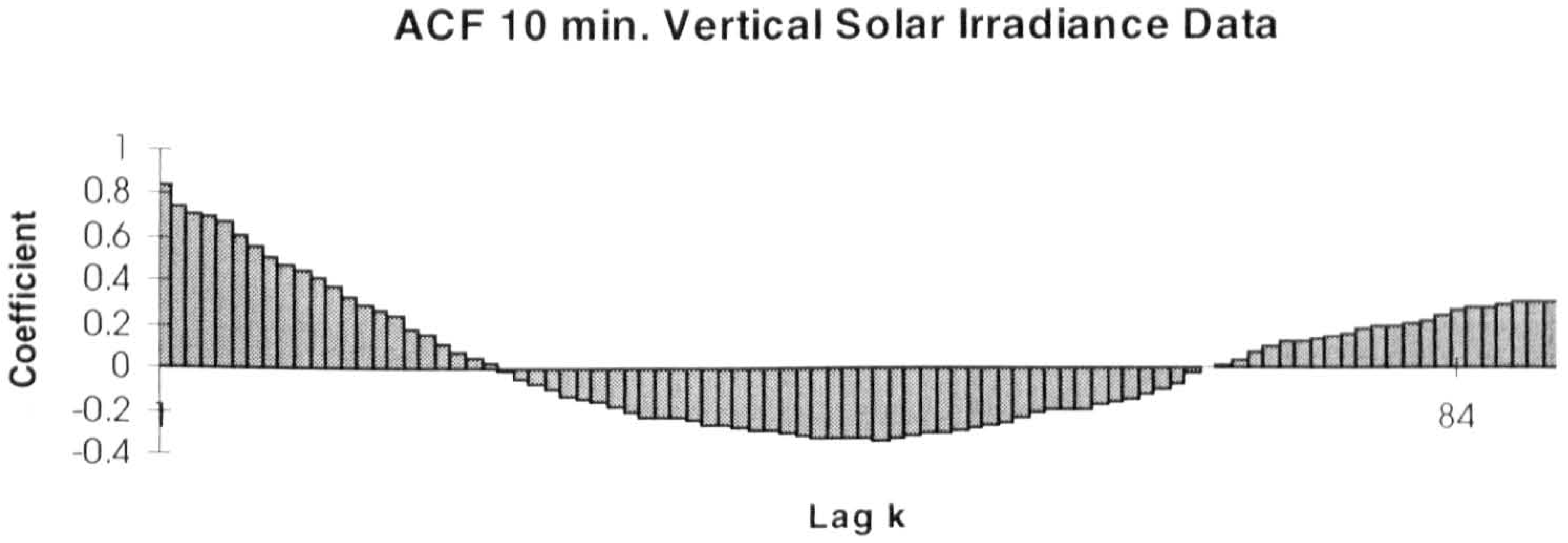


Figure 4.21.3 Vertical Solar Irradiance - 10 minute averages, JUN95_10

a)



b)



c)

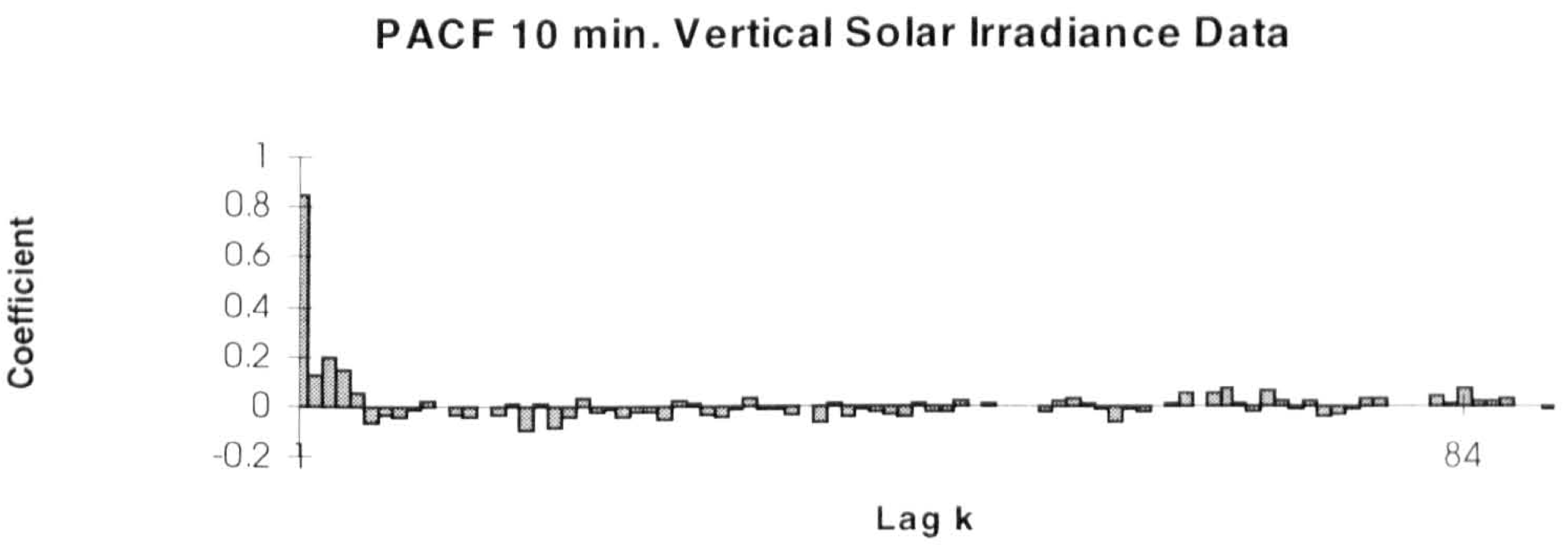
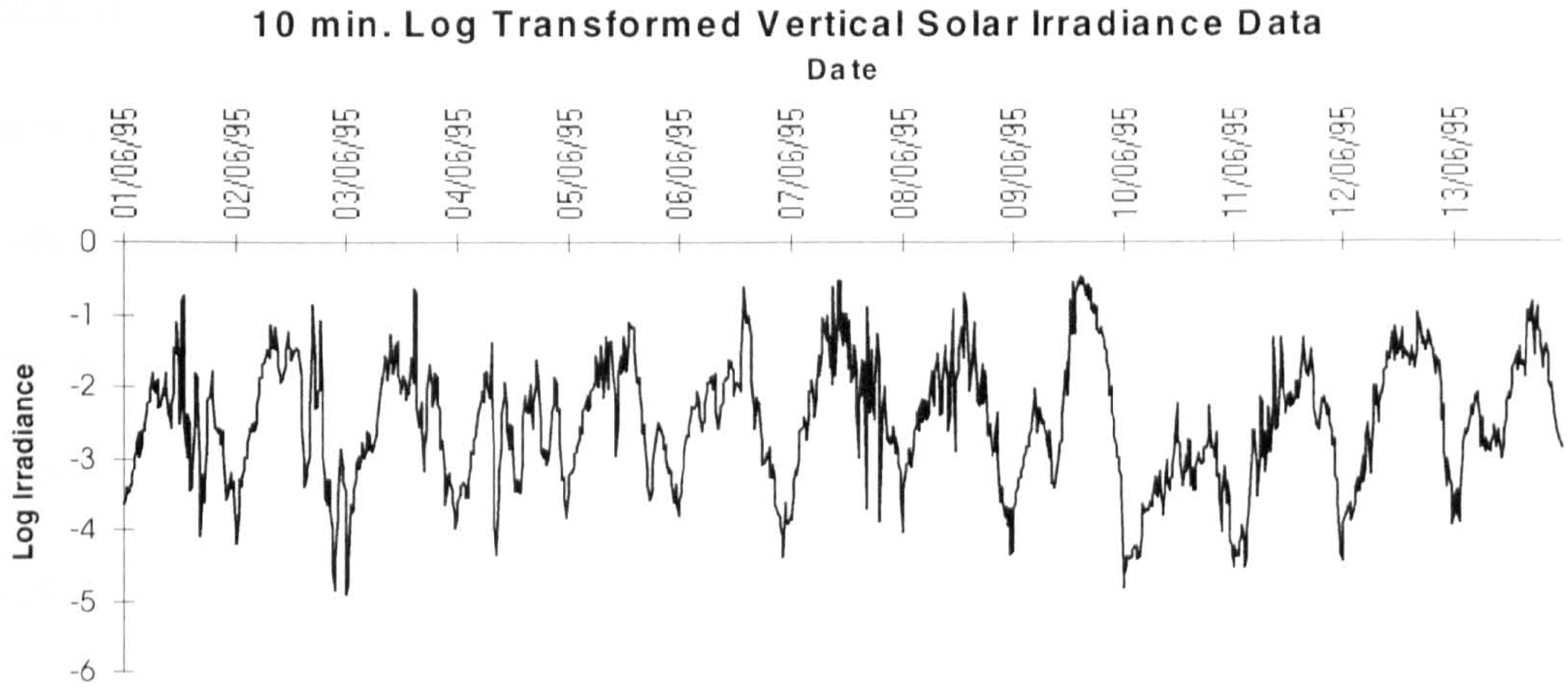
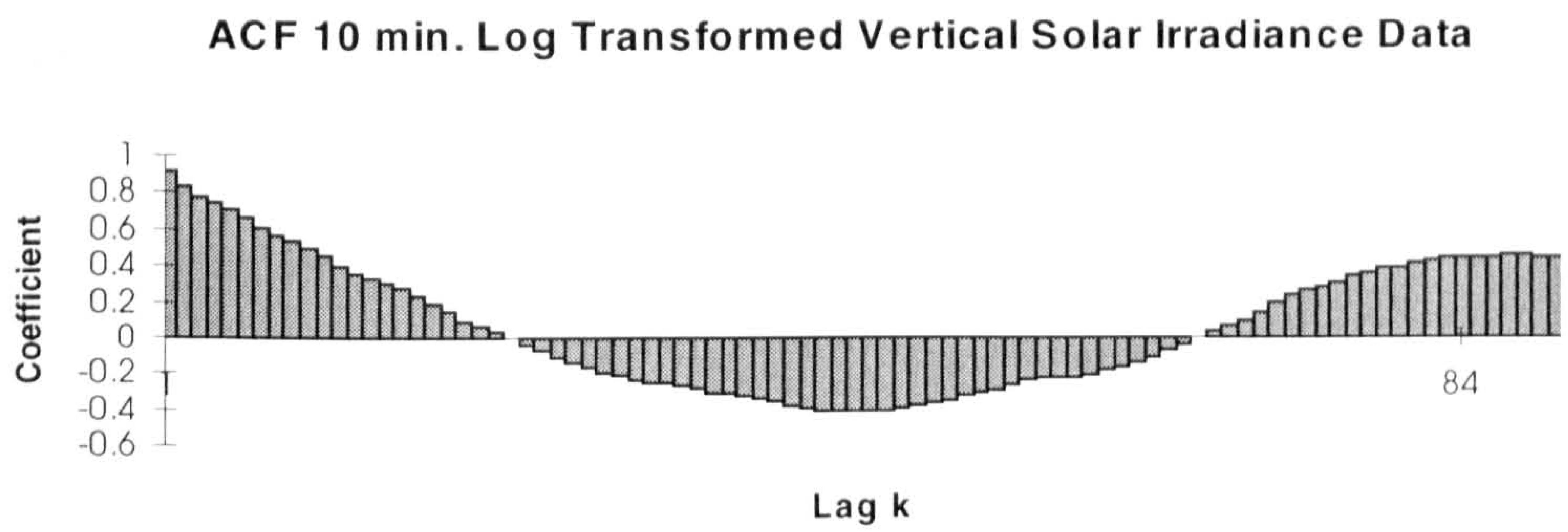


Figure 4.21.4 Log transformed Vertical Solar Irradiance - 10 minute averages, JUN95_10

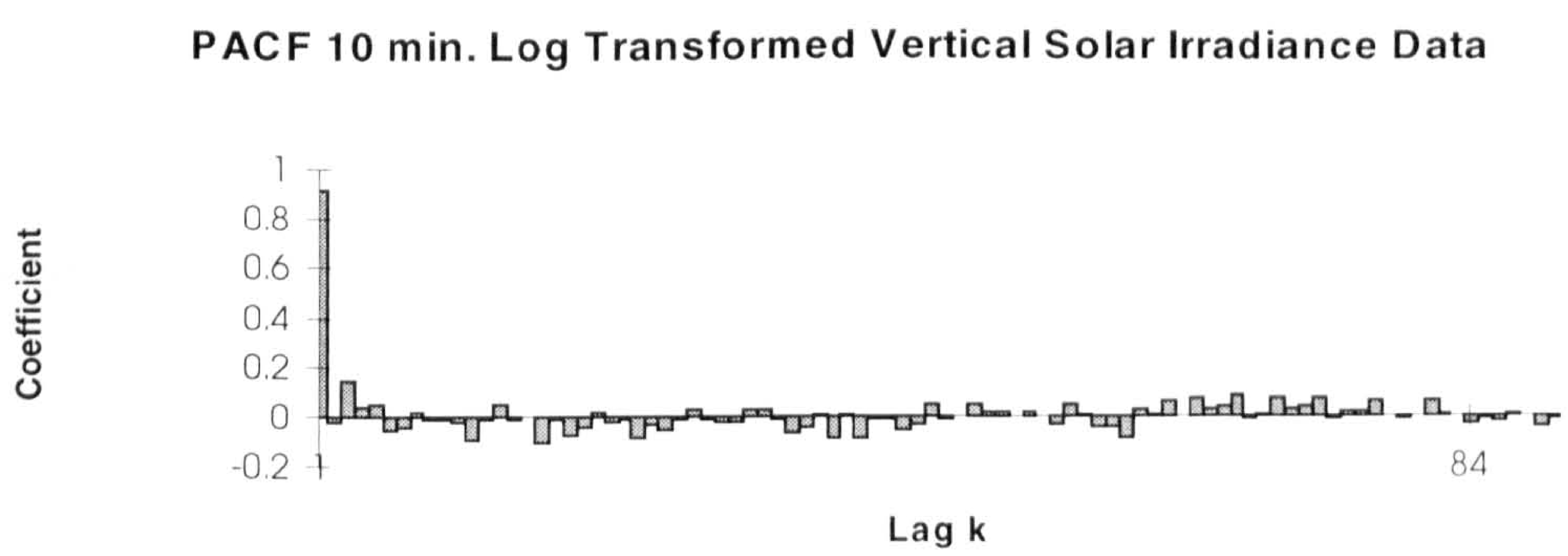
a)



b)



c)



4.22. June 1995 (1st - 13th) - Twenty minute averages

This data set, known as JUN95_10, contains 10 minute averaged Horizontal and Vertical Solar Irradiance data recorded between 1st and 13th June 1995.

4.22.1. Horizontal Solar Irradiance

The time series plot, Figure 4.22.1(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.22.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.22.1(b) and the structure of the ACF and PACF, Figure 4.22.1(b) & (c), an ARIMA(2,0,0) model was fitted to the data. This model accounted for 67% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.22.1(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 66% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the above models but there was no significant improvement.

4.22.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.22.2(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.22.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.22.2(b), and the structure of the ACF and PACF, Figure 4.22.2(b) & (c), an ARIMA(1,0,0) model was

fitted to the data. This model accounted for 74% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.22.2(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 72% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the above models but there was no significant improvement.

4.22.3. Vertical Solar Irradiance

The time series plot, Figure 4.22.3(a) displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.22.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.22.3(b), and the structure of the ACF and PACF, Figure 4.22.3(b) & (c), an ARIMA(2,0,0) model was fitted to the data. This model accounted for 69% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.22.3(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 67% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the above models but there was no significant improvement.

4.22.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.22.4(a), displays the daily cyclic nature of the data with 42 observations per day. The ACF of the data, Figure 4.22.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 42. From the autocorrelation and partial autocorrelation coefficients, Table 4.22.4(b), and the structure of the ACF and PACF, Figure 4.22.4(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 76% of the total variance and the AICF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.22.4(b) an ARIMA(2,1,0) model was fitted to the data. This model accounted for 75% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the above models but there was no significant improvement.

Table 4.22.1 Summary information for Horizontal Solar Irradiance - 20 minute averages (datafile JUN95_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2274	0.1615	0.0166	0.9094

b)

$2/\sqrt{546} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.808	0.808	-0.304	-0.304
2	0.733	0.229	0.011	-0.090
3	0.654	0.036	0.052	0.031
4	0.555	-0.083	-0.063	-0.039
42	0.308	0.061	0.043	-0.028

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)	AR1	0.6234	0.0418	14.93	4.63384	0.00853	67
	AR2	0.2316	0.0417	5.55			
	CONST	0.03246	0.00395	8.21			
ARIMA(2,0,0)(1,0,0)42	AR1	0.6185	0.0418	14.78	4..61228	0.00851	67
	AR2	0.2298	0.0418	5.50			
	SAR42	0.0706	0.0436	1.62			
	CONST	0.03159	0.00395	8.00			
ARIMA(1,1,0)	AR1	-0.3045	0.0408	-7.46	4.90966	0.00903	65
ARIMA(2,1,0)	AR1	-0.3320	0.0427	-7.77	4.86976	0.00897	66
	AR2	-0.0902	0.0428	-2.11			
ARIMA(1,1,0)(1,0,0)42	AR1	-0.3041	0.0409	-7.44	4.90162	0.00903	65
	SAR42	0.0412	0.0436	0.94			

Table 4.22.2 Summary information for Log Transformed Horizontal Solar Irradiance - 20 minute averages (datafile JUN95_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.7600	0.7963	-4.1014	-0.0950

b)

$2/\sqrt{546} = 0.086$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.857	0.857	-0.120	-0.120
2	0.750	0.054	-0.087	-0.103
3	0.667	0.047	0.033	0.009
4	0.575	-0.061	-0.025	-0.029
42	0.444	-0.050	0.053	0.029

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)	AR1	0.8607	0.0219	39.32	90.3060	0.1660	73
	CONST	-0.2473	0.01744	-14.18			
ARIMA(1,0,0)(1,0,0)42	AR1	0.8479	0.0229	36.98	89.3927	0.1646	74
	SAR42	0.1053	0.0434	2.43			
	CONST	-0.2411	0.01737	-13.88			
ARIMA(2,1,0)	AR1	-0.1322	0.0427	-3.10	94.8002	0.1746	72
	AR2	-0.1031	0.0427	-2.41			
ARIMA(2,1,0)(1,0,0)42	AR1	-0.1402	0.0429	-3.27	94.1072	0.1736	72
	AR2	-0.1129	0.0427	-2.64			
	SAR42	0.0870	0.0436	2.00			

Table 4.22.3 Summary information for Vertical Solar Irradiance - 20 minute averages (datafile JUN95_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1172	0.1006	0.0084	0.5960

b)

$2/\sqrt{546} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.817	0.817	-0.316	-0.316
2	0.749	0.245	0.056	-0.048
3	0.661	-0.005	0.038	0.046
4	0.559	-0.099	-0.071	-0.048
42	0.286	0.088	0.053	-0.046

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,0,0)	AR1	0.6169	0.0416	14.84	1.71016	0.00315	69
	AR2	0.2474	0.0416	5.95			
	CONST	0.0156	0.0024	6.49			
ARIMA(2,0,0)(1,0,0)42	AR1	0.6151	0.0417	14.75	1.69984	0.00314	69
	AR2	0.2434	0.0417	5.84			
	SAR42	0.0793	0.0438	1.81			
	CONST	0.01499	0.00239	6.25			
ARIMA(1,1,0)	AR1	-0.3156	0.0407	-7.76	1.80383	0.00332	67
ARIMA(2,1,0)	AR1	-0.3308	0.0429	-7.72	1.79966	0.00331	67
	AR2	-0.0481	0.0429	-1.12			
ARIMA(1,1,0)(1,0,0)42	AR1	-0.3148	0.0408	-7.72	1.79958	0.00331	67
	SAR42	0.0496	0.0439	1.13			

Table 4.22.4 Summary information for Log Transformed Vertical Solar Irradiance - 20 minute averages (datafile JUN95_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.4837	0.8523	-4.7855	-0.5175

b)

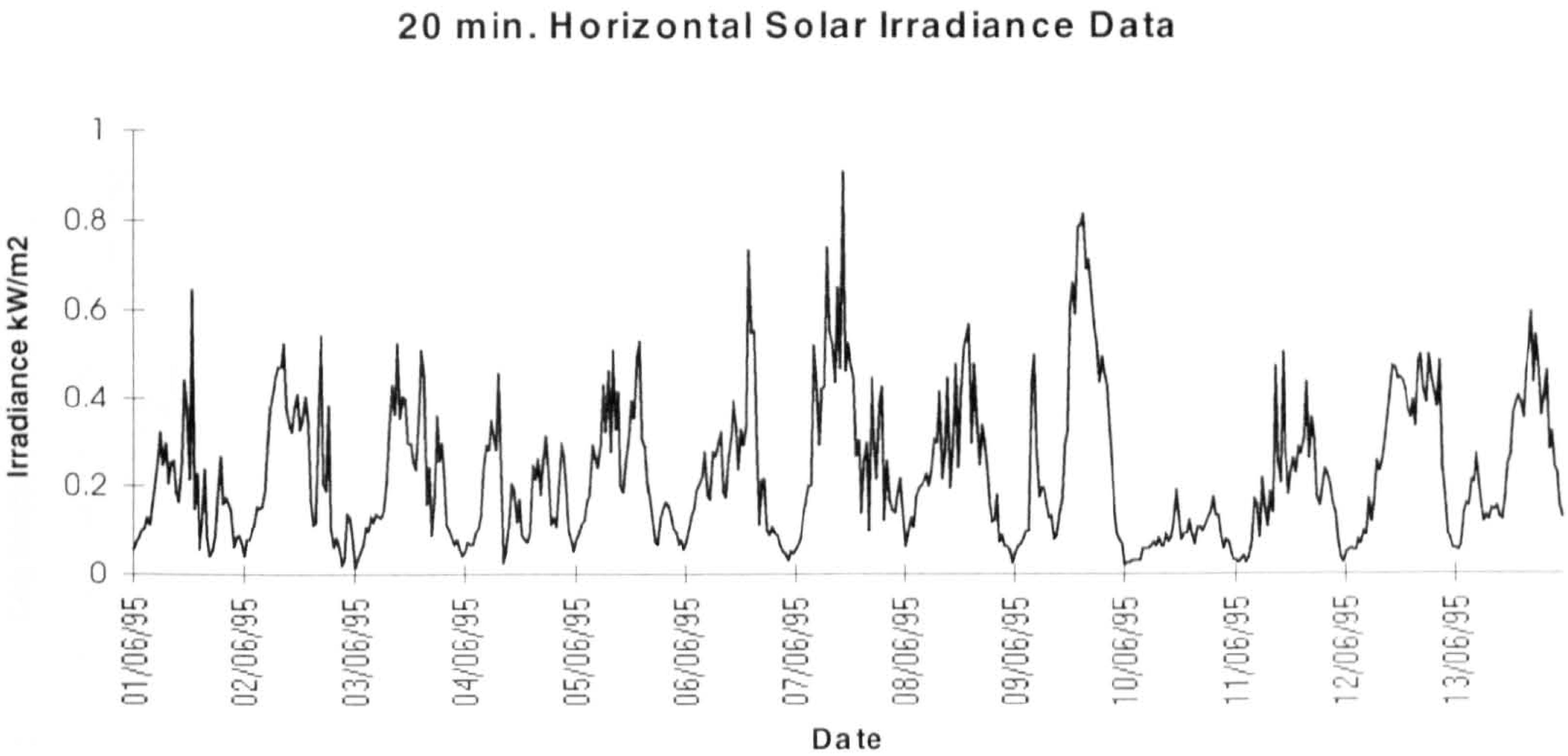
$2/\sqrt{546} = 0.086$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.873	0.873	-0.105	-0.105
2	0.774	0.046	-0.061	-0.073
3	0.689	0.020	0.037	0.023
4	0.596	-0.073	0.050	-0.048
42	0.466	-0.028	0.067	0.039

c)

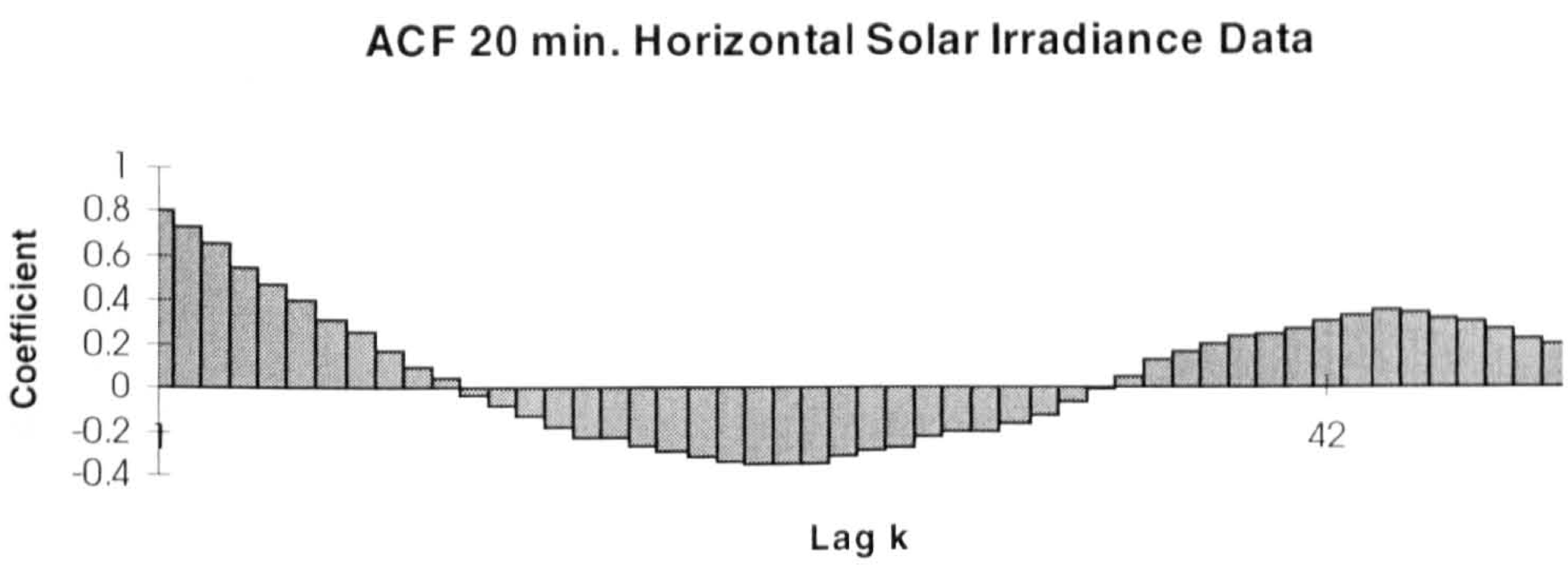
model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)	AR1	0.8765	0.0207	42.29	92.6547	0.1703	76
	CONST	-0.3092	0.01767	-17.50			
ARIMA(1,0,0)(1,0,0)42	AR1	0.8604	0.0220	39.18	91.3621	0.1683	77
	SAR42	0.1360	0.0433	3.14			
	CONST	-0.3013	0.01756	-17.16			
ARIMA(1,1,0)	AR1	-0.1052	0.0426	-2.47	97.7759	0.1797	75
ARIMA(2,1,0)	AR1	-0.1129	0.0428	-2.64	97.2589	0.1791	75
	AR2	-0.0727	0.0428	-1.70			
ARIMA(1,1,0)(1,0,0)42	AR1	-0.1108	0.0427	-2.59	97.0151	0.1787	75
	SAR42	0.0895	0.0434	2.06			

Figure 4.22.1 Horizontal Solar Irradiance - 20 minute averages, JUN95_20

a)



b)



c)

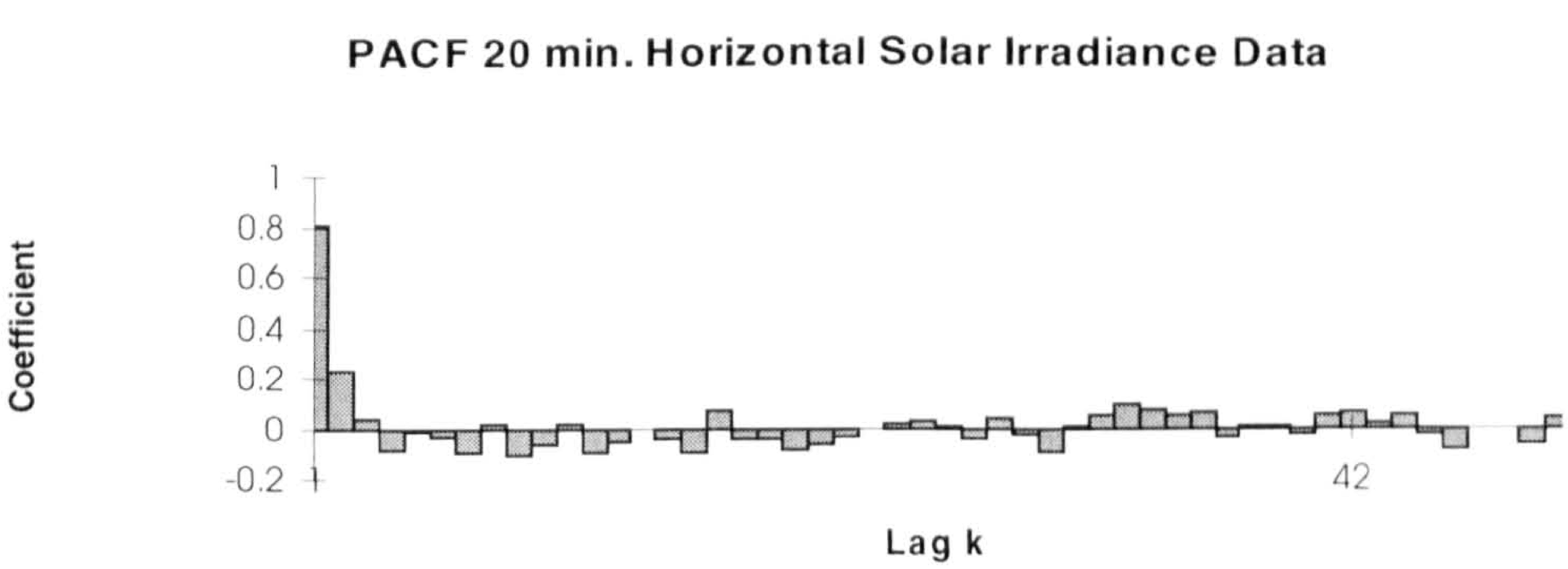
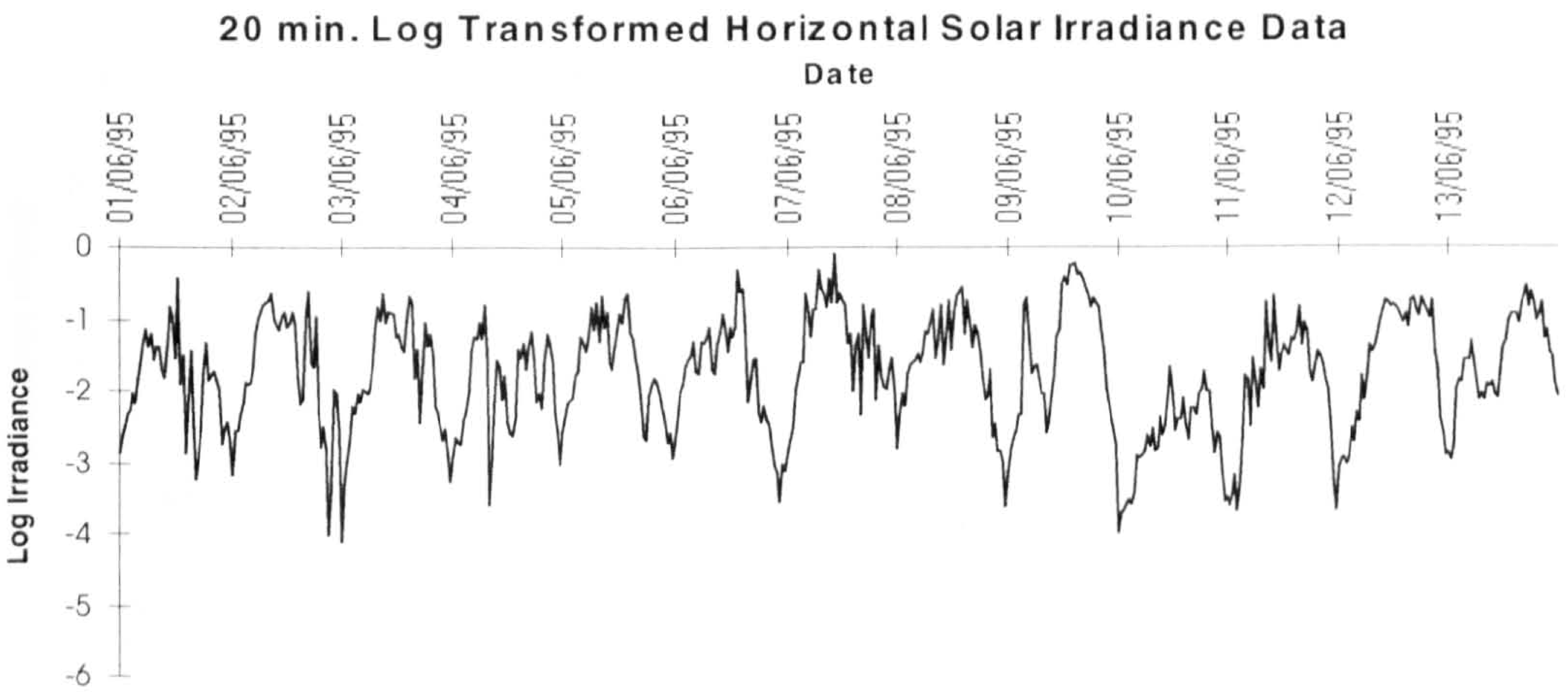
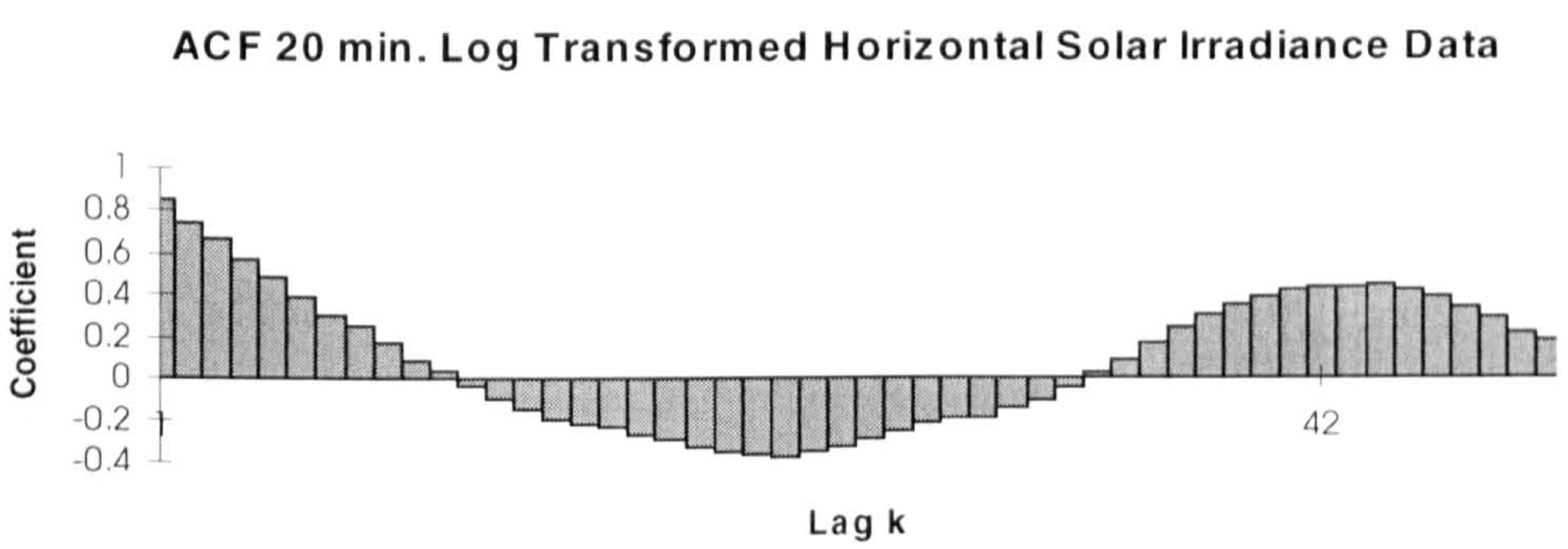


Figure 4.22.2 Log transformed Horizontal Solar Irradiance - 20 minute averages, JUN95_20

a)



b)



c)

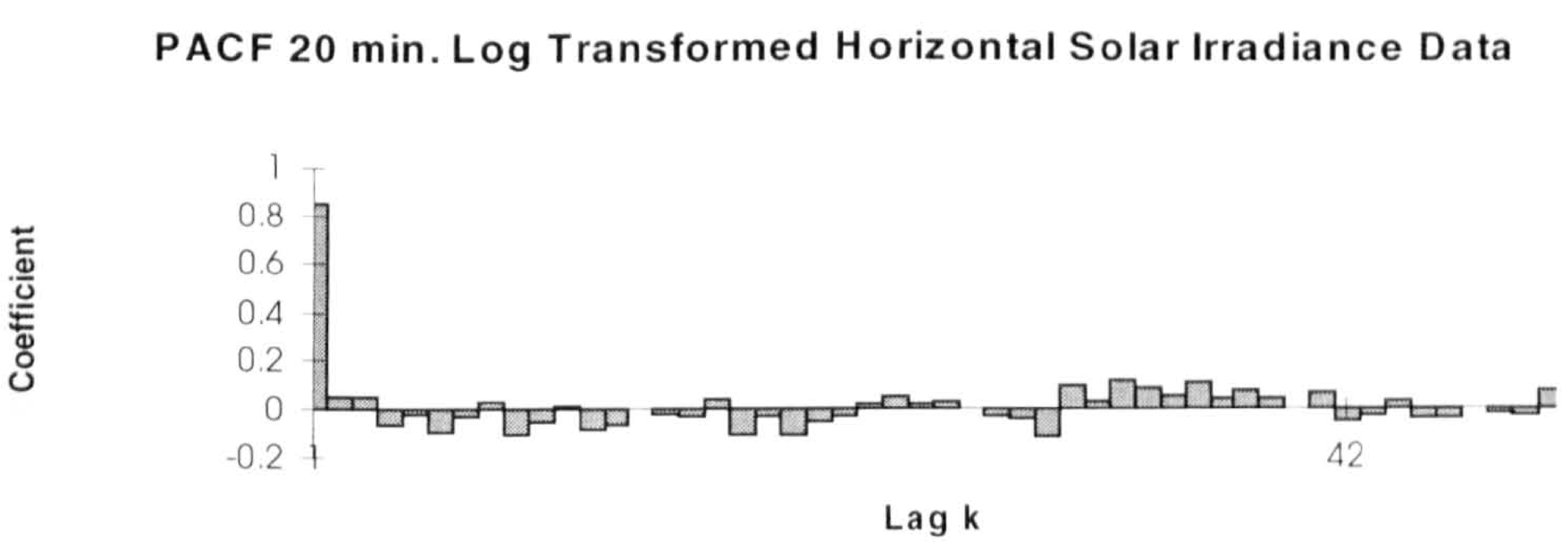
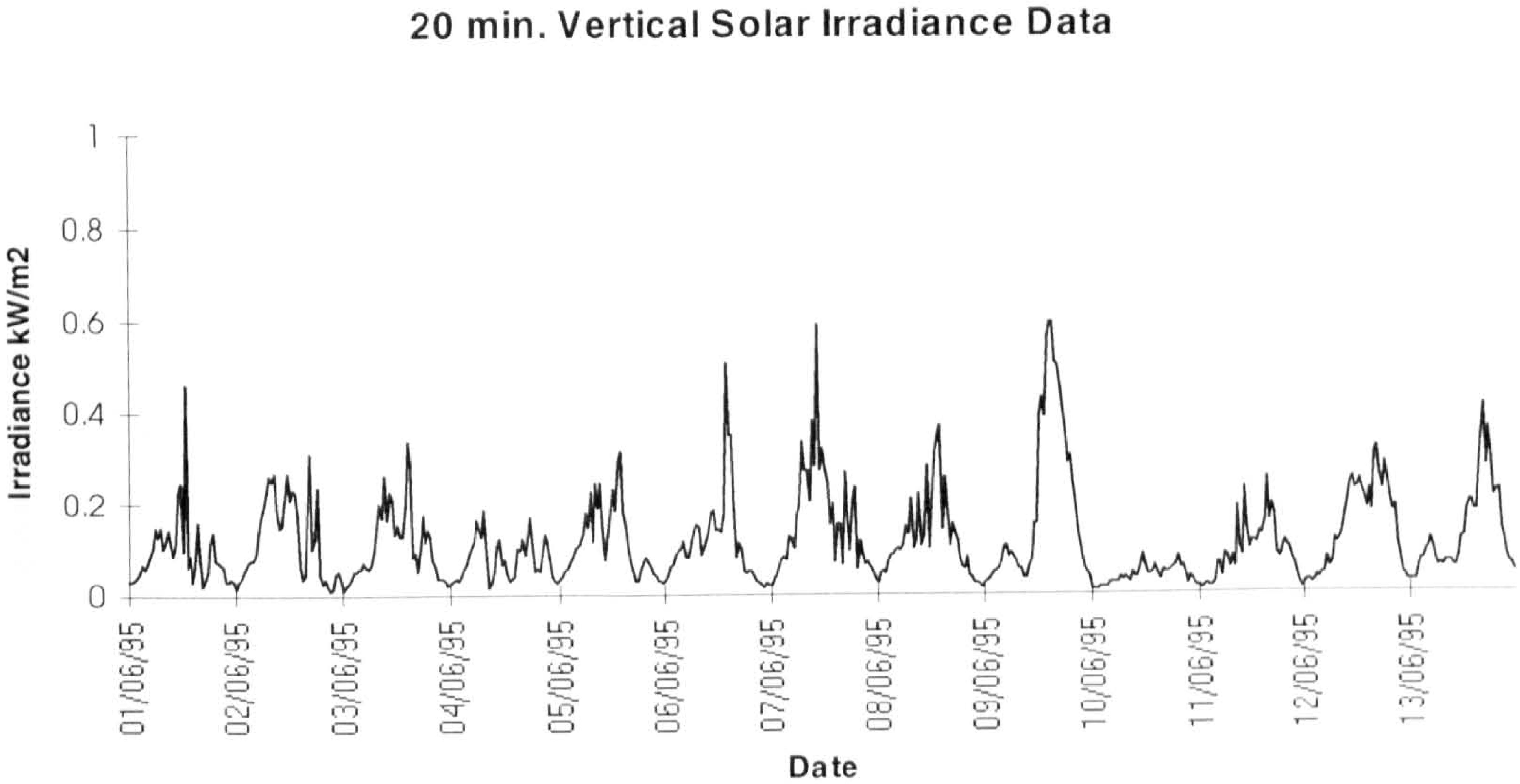
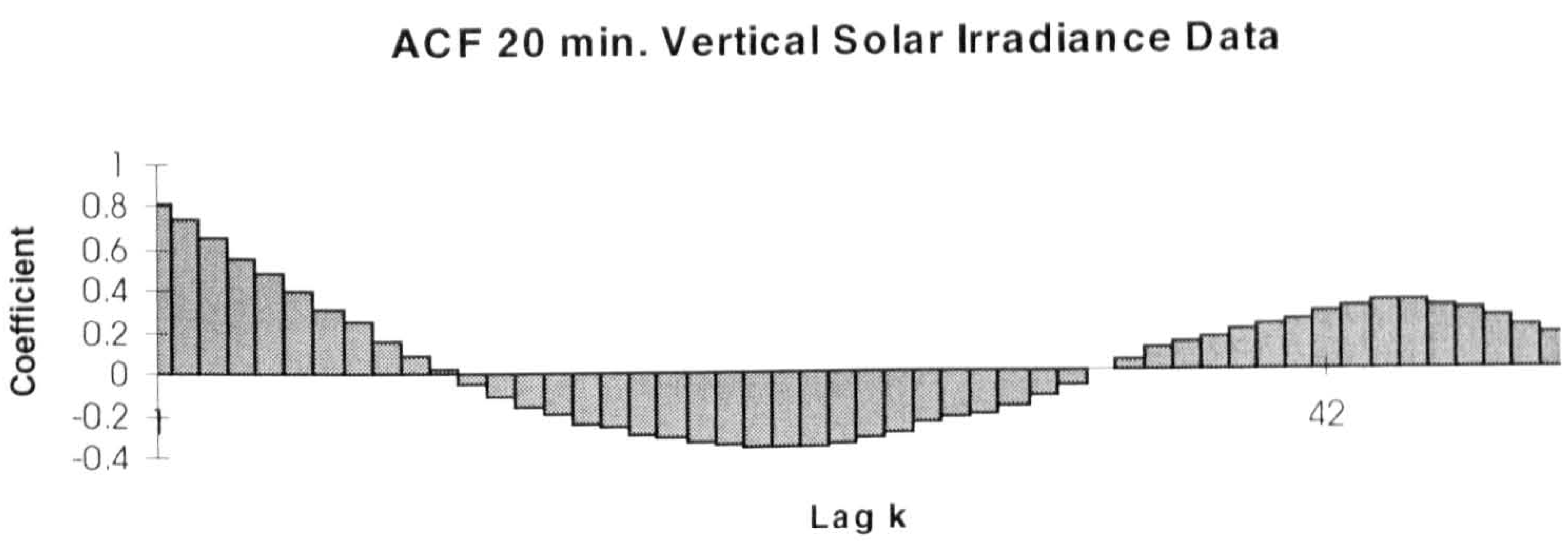


Figure 4.22.3 Vertical Solar Irradiance - 20 minute averages, JUN95_20

a)



b)



c)

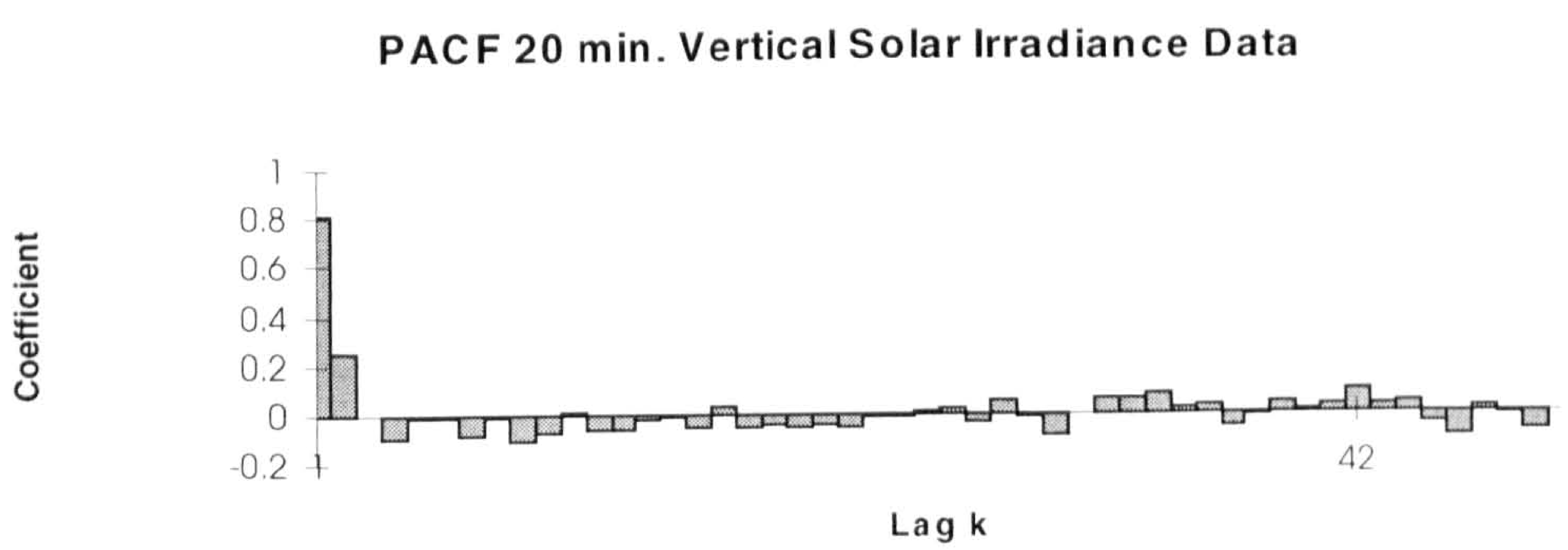
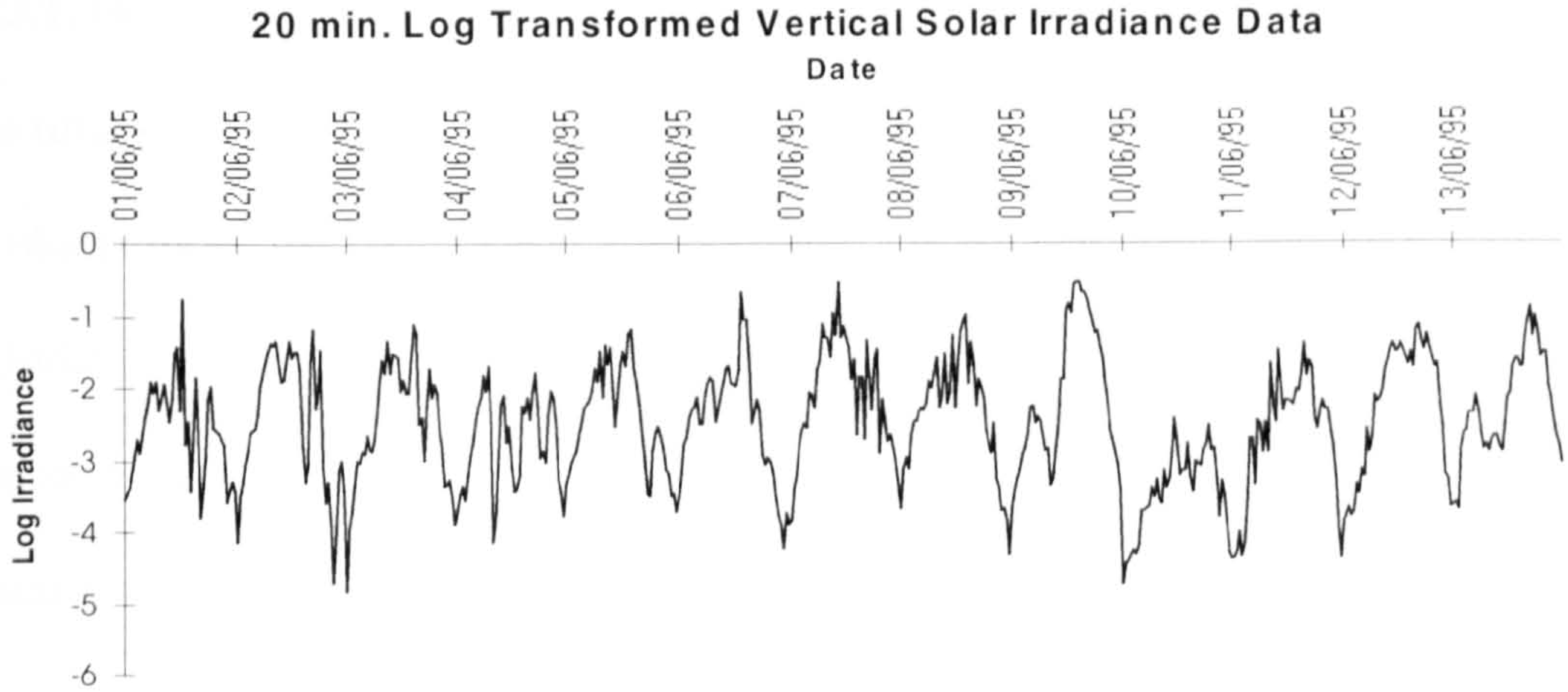
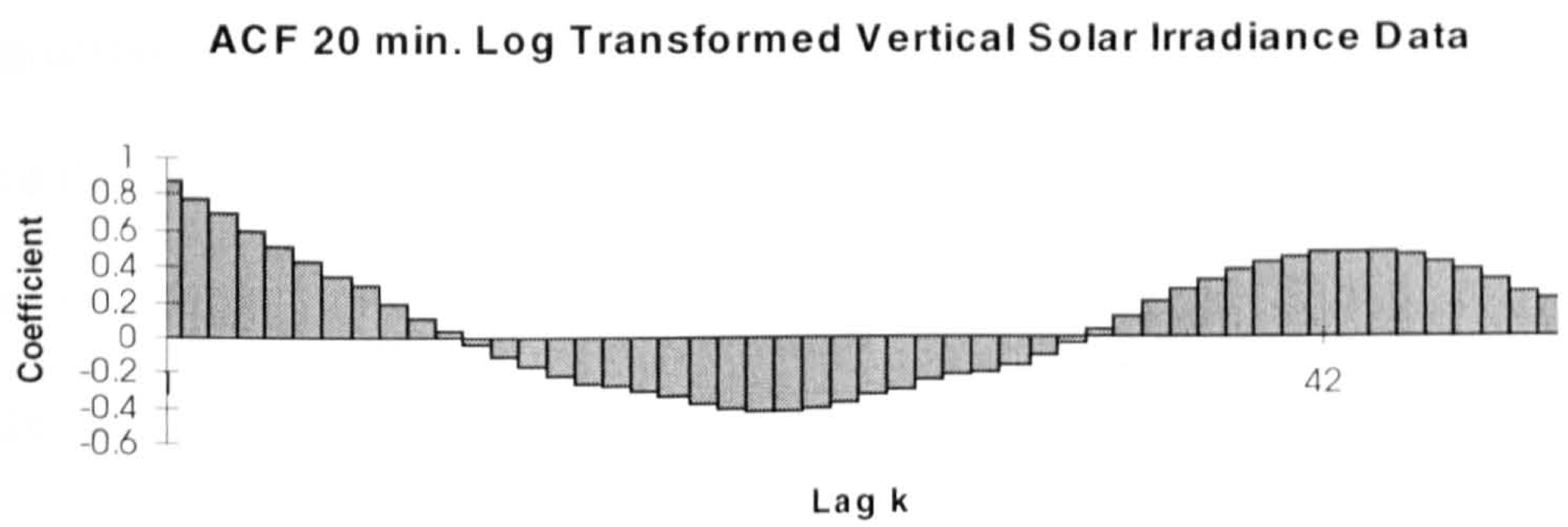


Figure 4.22.4 Log transformed Vertical Solar Irradiance - 20 minute averages, JUN95_20

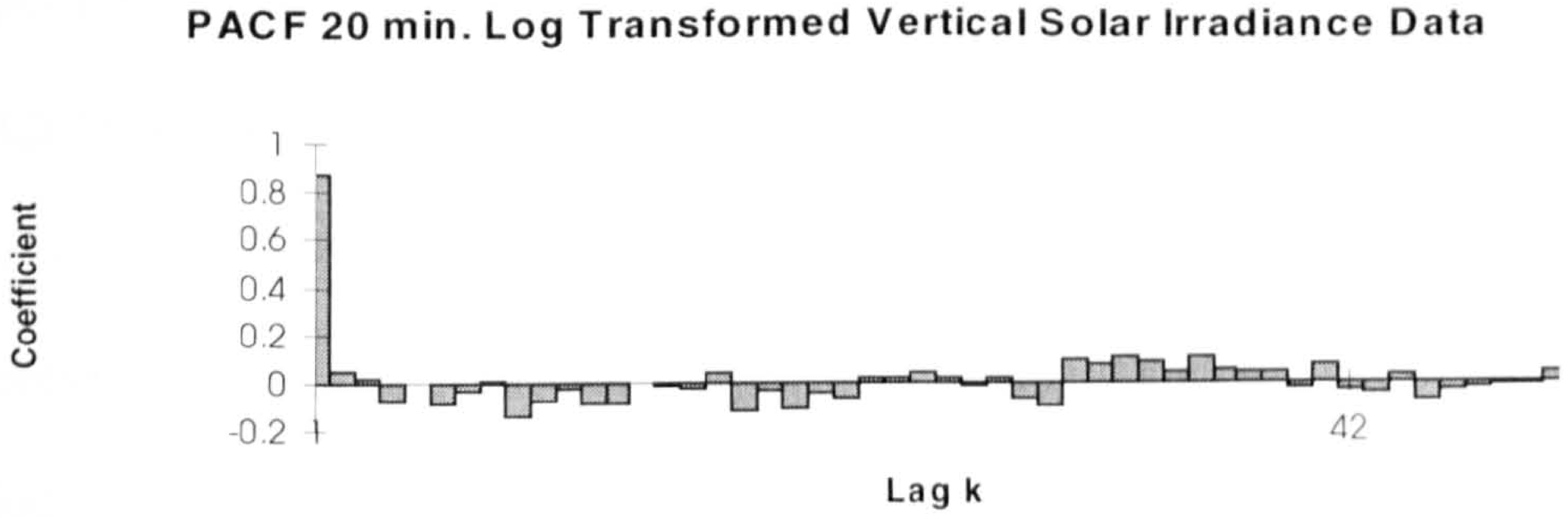
a)



b)



c)



4.23. June 1995 (1st - 13th) - Thirty minute averages

This data set, known as JUN95_30, contains 30 minute averaged Horizontal and Vertical Solar Irradiance data recorded between 1st and 13th June 1995.

4.23.1. Horizontal Solar Irradiance

The time series plot, Figure 4.23.1(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.23.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.23.1(b), and the structure of the ACF and PACF, Figure 4.23.1(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 66% of the total variance but the ACF of the residuals had a significant value at lag 2. An ARIMA(2,0,0) model was fitted to the data, accounted for 67% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.23.1(b) an ARIMA(1,1,0) model was fitted to the data. This model accounted for 64% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the above models. The ARIMA(1,0,0)(1,0,0)28 model accounted for 67% of the total variance.

4.23.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.23.2(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.23.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.23.2(b), and the structure of the ACF PACF, Figure 4.23.2(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 71% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.23.2(b) the ACF and the PACF of the differenced series do not exhibit any structure and an ARIMA model cannot be determined.

A seasonal AR parameter was included in the ARIMA(1,0,0) model. This ARIMA(1,0,0)(1,0,0)28 model also accounted for 71%.

4.23.3. Vertical Solar Irradiance

The time series plot, Figure 4.23.3(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.23.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.23.3(b), and the structure of the ACF and PACF, Figure 4.23.3(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 69% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.23.3(b) an ARIMA(1,1,0) model was fitted to the data. This model accounted for 67% of the total variance and the ACF of the residuals showed no structure.

A seasonal AR parameter was included in the ARIMA(1,1,0) model, this model also accounted for 67% of the total variance.

4.23.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.23.4(a), displays the daily cyclic nature of the data with 28 observations per day. The ACF of the data, Figure 4.23.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 28. From the autocorrelation and partial autocorrelation coefficients, Table 4.23.4(b), and the structure of the ACF and PACF, Figure 4.23.4(b) & (c), an ARIMA(1,0,0) model was fitted to the data. This model accounted for 74% of the total variance, but the ACF of the residuals was not consistent with a 'white noise' process and further investigation is required.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.23.4(b) the ACF and the PACF of the differenced series do not exibit any structure and an ARIMA model cannot be determined

A seasonal AR parameter was included in the ARIMA(1,0,0) model and fitted to the data, this model also accounted for 74% of the total variance and was not a significant improvement on the ARIMA(1,0,0) model.

Table 4.23.1 Summary information for Horizontal Solar Irradiance - 30 minute averages (datafile JUN95_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2274	0.1574	0.0184	0.8023

b)

$2/\sqrt{364} = 0.105$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.814	0.814	-0.159	-0.159
2	0.688	0.074	0.049	0.024
3	0.545	-0.103	-0.056	-0.046
4	0.423	-0.038	-0.015	-0.033
28	0.322	0.101	0.044	-0.068

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8176	0.0303	26.29	2.99821	0.00828	66
	CONST	0.0409	0.0048	8.85			
ARIMA(2,0,0)	AR1	0.7574	0.0525	14.42	2.98185	0.00826	67
	AR2	0.0739	0.0525	1.41			
	CONST	0.0377	0.0048	7.92			
ARIMA(1,0,0)(1,0,0)28	AR1	0.8085	0.0310	26.05	2.97874	0.00825	67
	SAR28	0.0821	0.0536	1.53			
	CONST	0.03948	0.00476	8.29			
ARIMA(1,1,0)	AR1	-0.1588	0.0519	-3.06	3.21875	0.00889	64
ARIMA(1,1,0)(1,0,0)28	AR1	-0.1598	0.0521	-3.07	3.2113	0.00890	64
	SAR28	0.0492	0.0538	0.91			

Table 4.23.2 Summary information for Log Transformed Horizontal Solar Irradiance - 30 minute averages (datafile JUN95_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.7483	0.7810	-3.9936	-0.2203

b)

$2/\sqrt{364} = 0.105$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.841	0.841	-0.032	-0.032
2	0.693	-0.047	-0.049	-0.050
3	0.562	-0.029	0.071	0.068
4	0.410	-0.153	-0.115	-0.114
28	0.465	0.004	0.068	0.023

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)	AR1	0.8450	0.0282	29.96	63.9256	0.1766	71
	CONST	-0.2739	0.0220	-12.44			
ARIMA(1,0,0)(1,0,0)28	AR1	0.8269	0.0298	27.77	62.9874	0.1745	71
	SAR28	0.1271	0.0533	2.39			
	CONST	-0.2663	0.0219	-12.16			

Table 4.23.3 Summary information for Vertical Solar Irradiance - 30 minute averages (datafile JUN95_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1172	0.0979	0.0098	0.5893

b)

$2/\sqrt{364} = 0.105$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.831	0.831	-0.105	-0.105
2	0.698	0.023	0.052	0.041
3	0.549	-0.122	-0.077	-0.069
4	0.426	0.016	-0.008	-0.025
28	0.299	0.126	0.063	-0.065

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)	AR1	0.8343	0.0291	28.70	1.0658	0.00294	69
	CONST	0.0191	0.0028	6.71			
ARIMA(1,0,0)(1,0,0)28	AR1	0.8248	0.0298	27.72	1.05631	0.00293	69
	SAR28	0.0996	0.0540	1.84			
	CONST	0.01816	0.00283	6.40			
ARIMA(1,1,0)	AR1	-0.1052	0.0523	-2.01	1.14988	0.00318	67
ARIMA(1,1,0)(1,0,0)28	AR1	-0.1058	0.0525	-2.01	1.14486	0.00317	67
	SAR28	0.0682	0.0544	1.25			

Table 4.23.4 Summary information for Log Transformed Vertical Solar Irradiance - 30 minute averages (datafile JUN95_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.4717	0.8401	-4.6220	-0.5288

b)

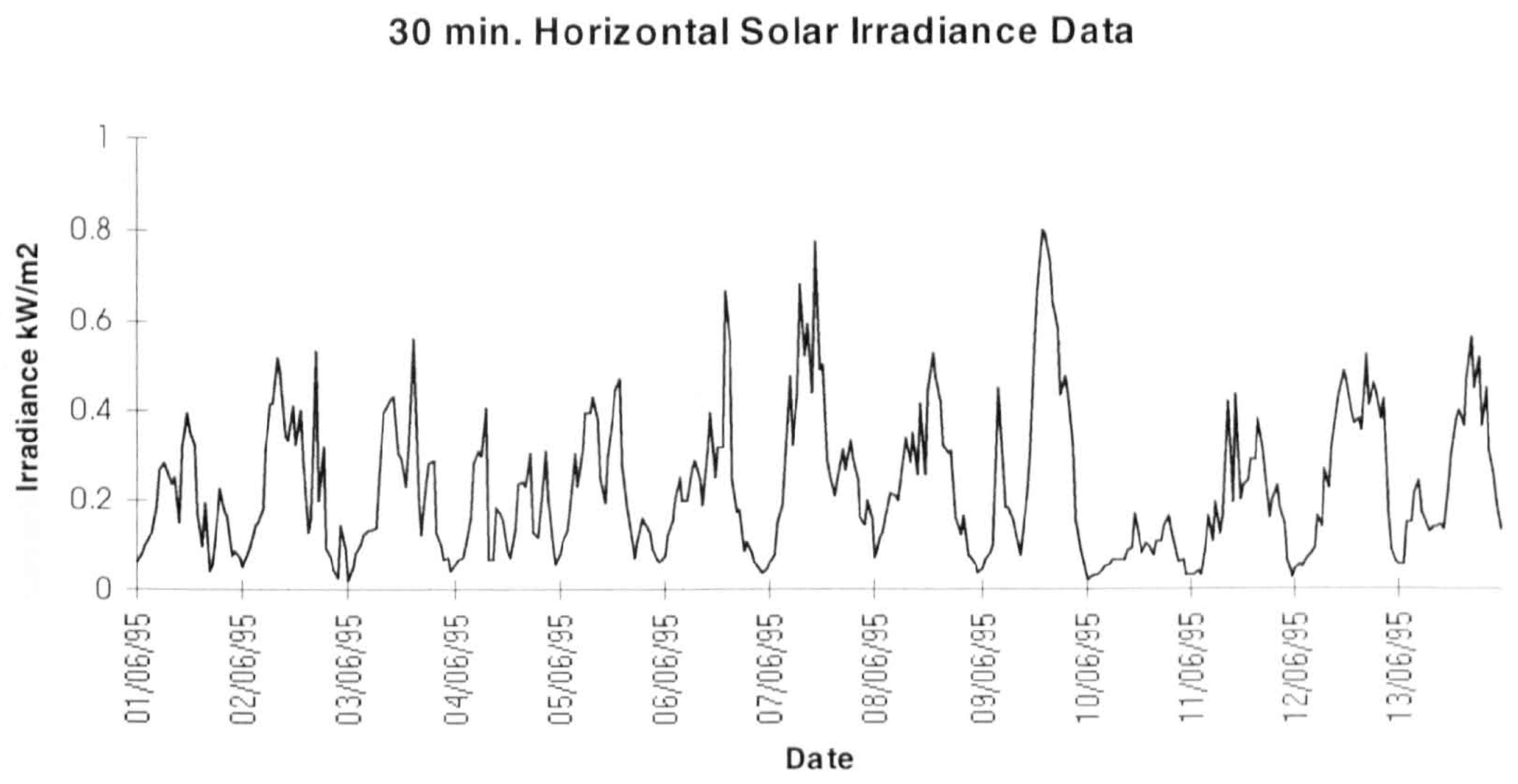
$2/\sqrt{364} = 0.105$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.857	0.857	0.006	0.006
2	0.713	-0.080	-0.043	-0.043
3	0.583	-0.032	0.046	0.047
4	0.442	-0.124	-0.101	-0.104
28	0.485	0.031	0.065	0.031

c)

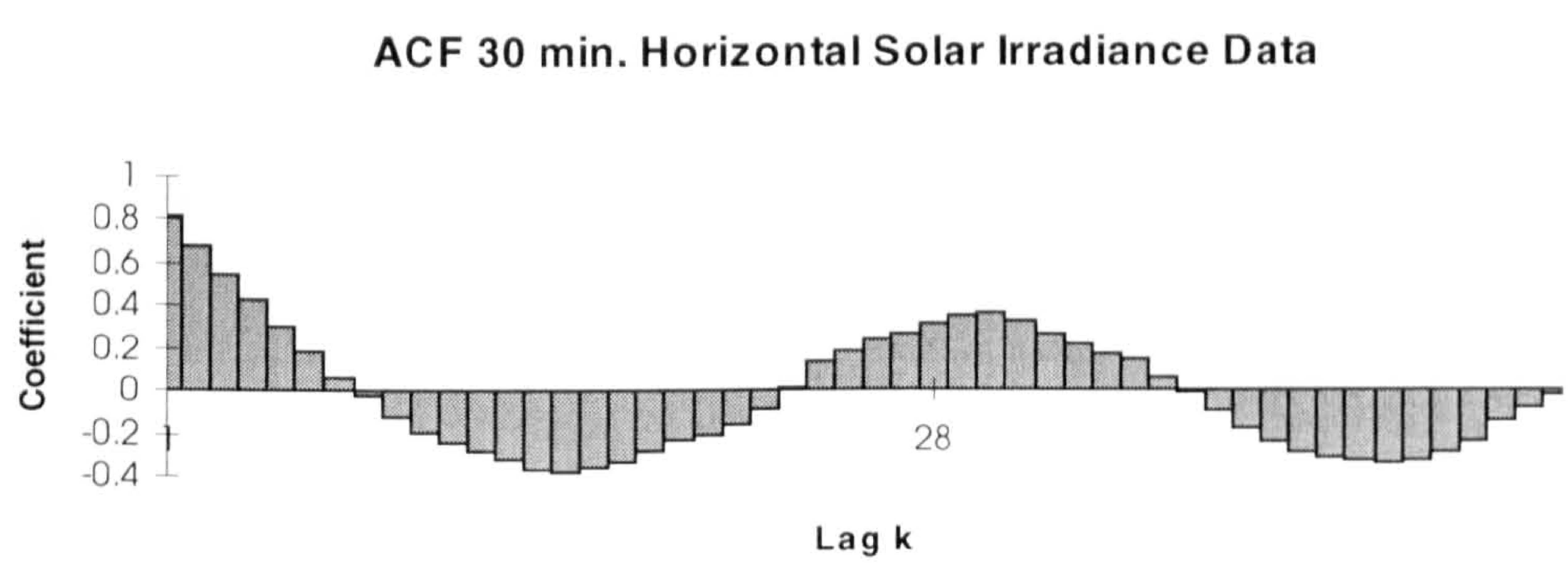
model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)	AR1	0.8614	0.0268	32.11	66.8641	0.1847	74
	CONST	-0.3460	0.0225	-15.35			
ARIMA(1,0,0)(1,0,0)28	AR1	0.8427	0.0284	29.65	65.9333	0.1826	74
	SAR28	0.1299	0.0534	2.43			
	CONST	-0.3407	0.0224	-15.21			

Figure 4.23.1 Horizontal Solar Irradiance - 30 minute averages, JUN95_30

a)



b)



c)

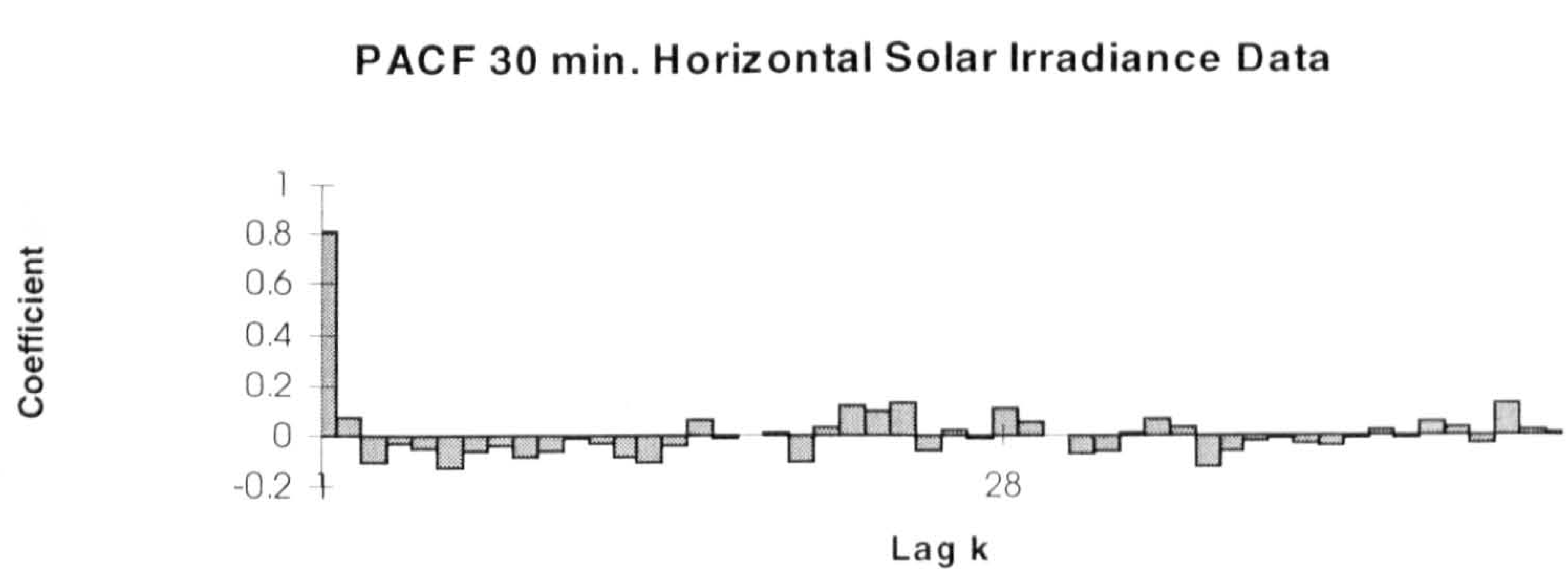
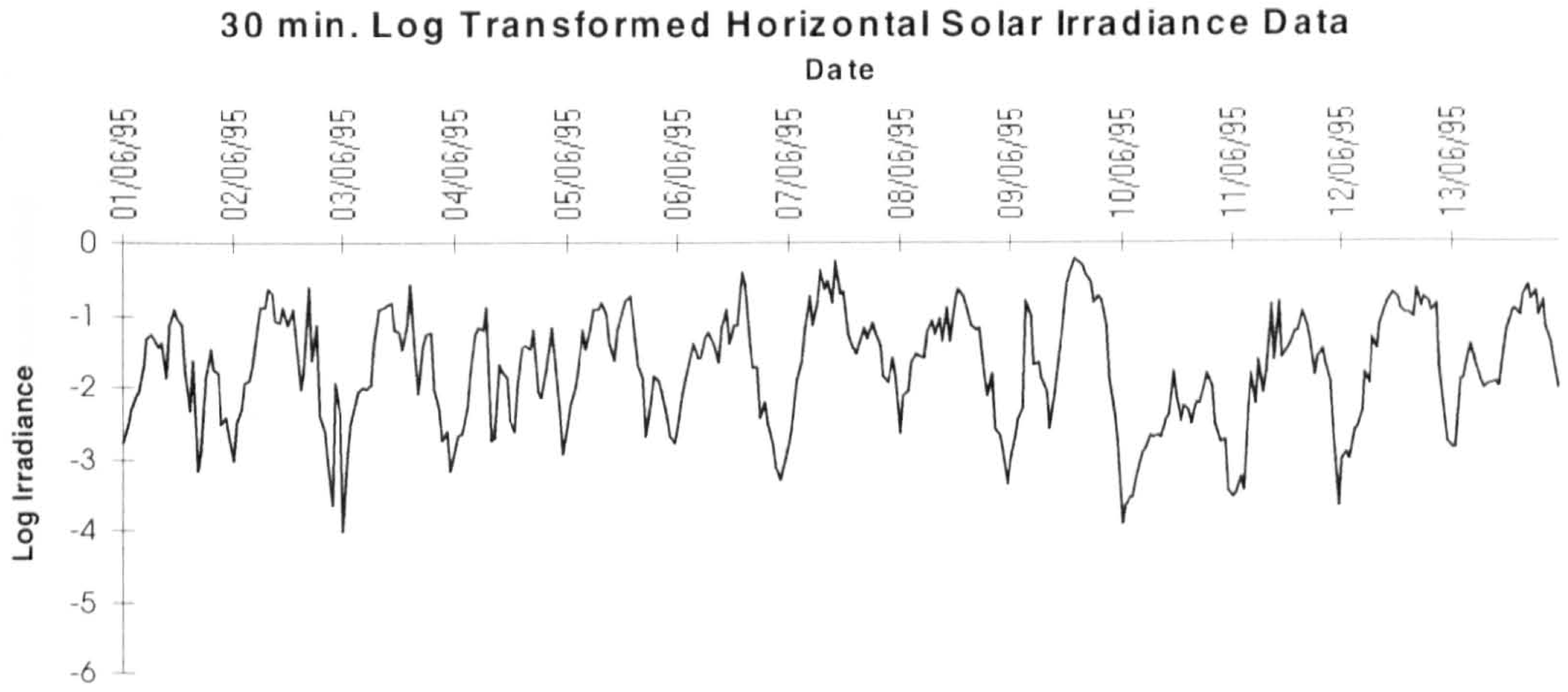
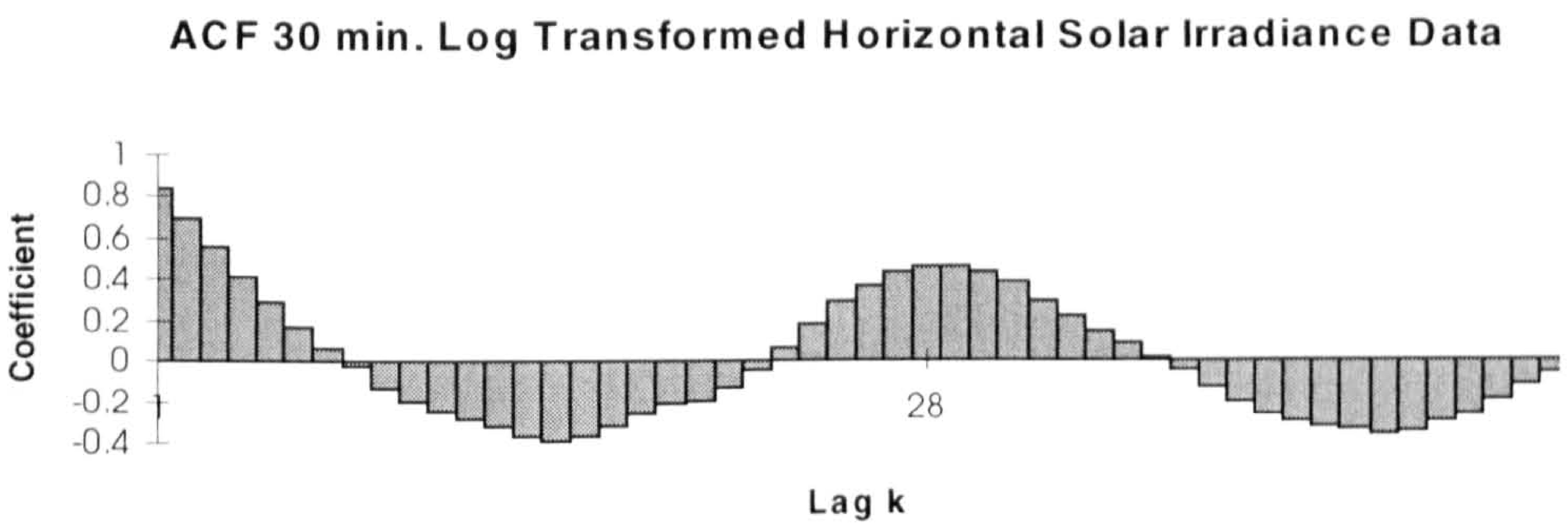


Figure 4.23.2 Log transformed Horizontal Solar Irradiance - 30 minute averages, JUN95_30

a)



b)



c)

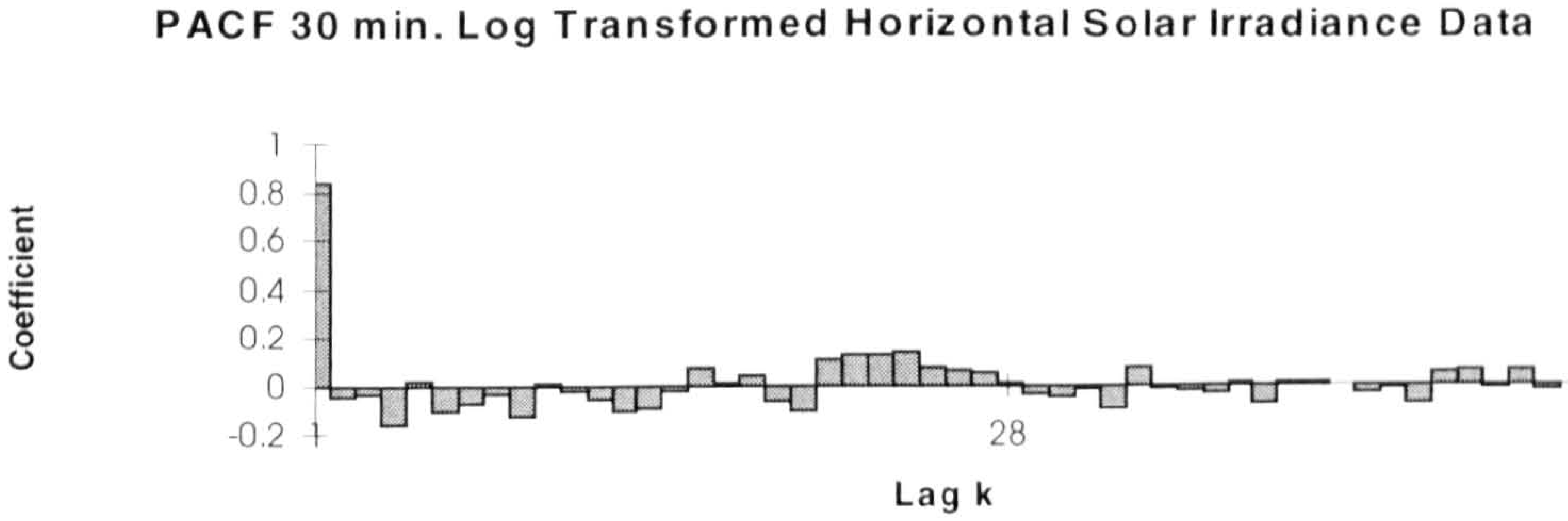
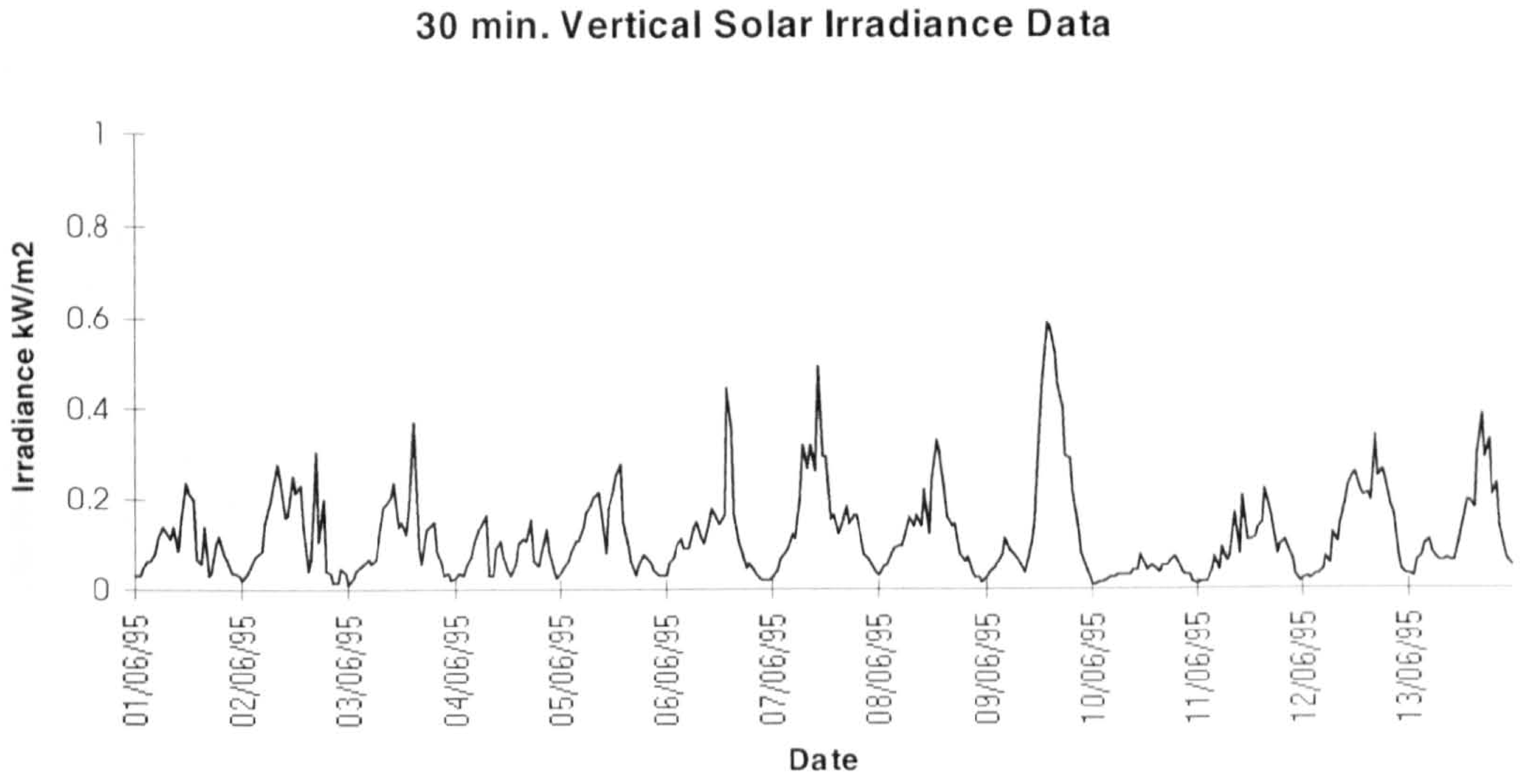
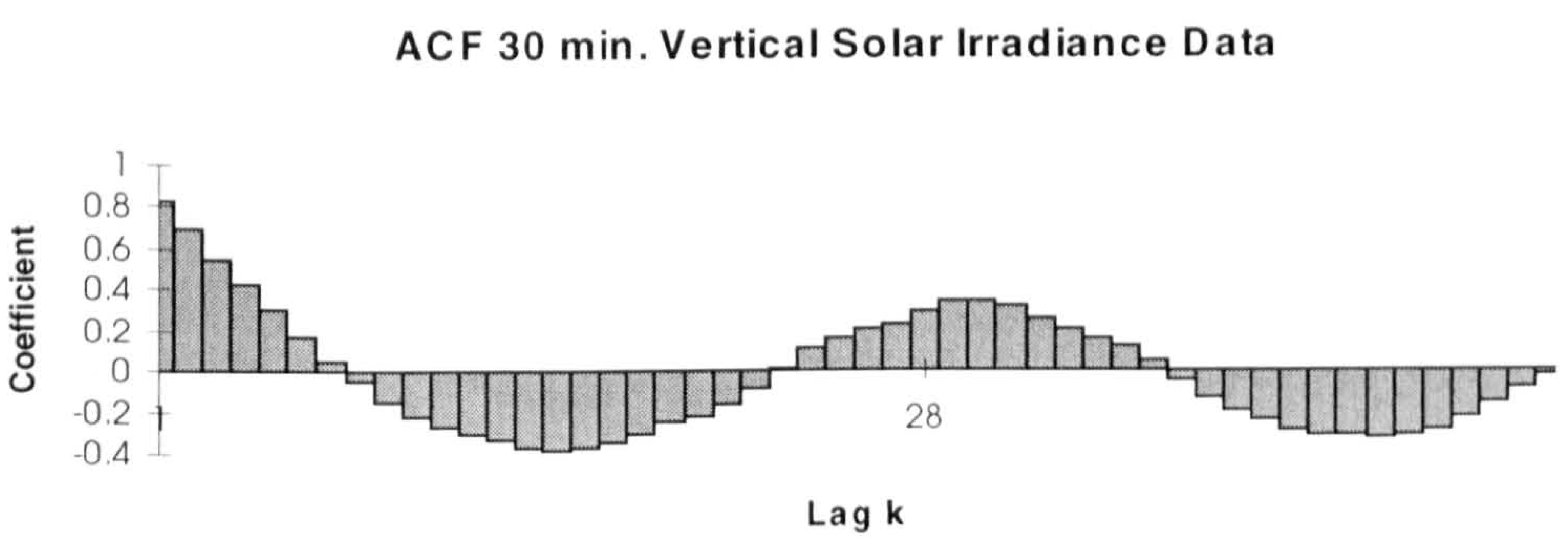


Figure 4.23.3 Vertical Solar Irradiance - 30 minute averages, JUN95_30

a)



b)



c)

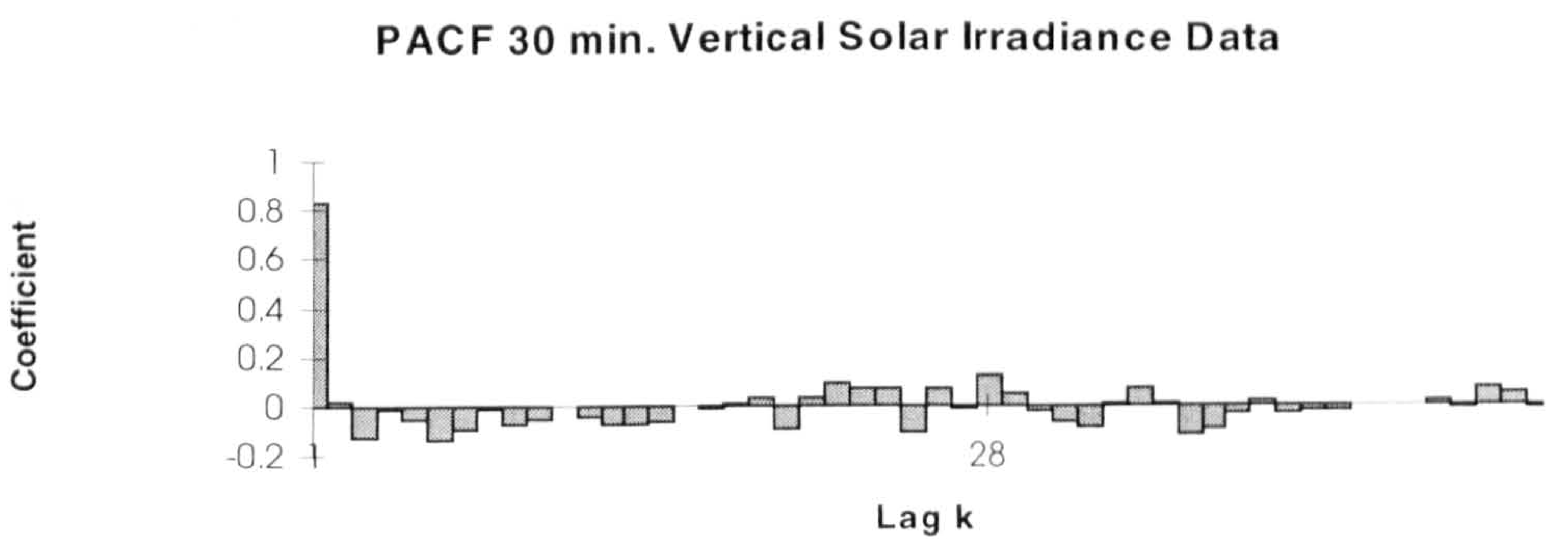
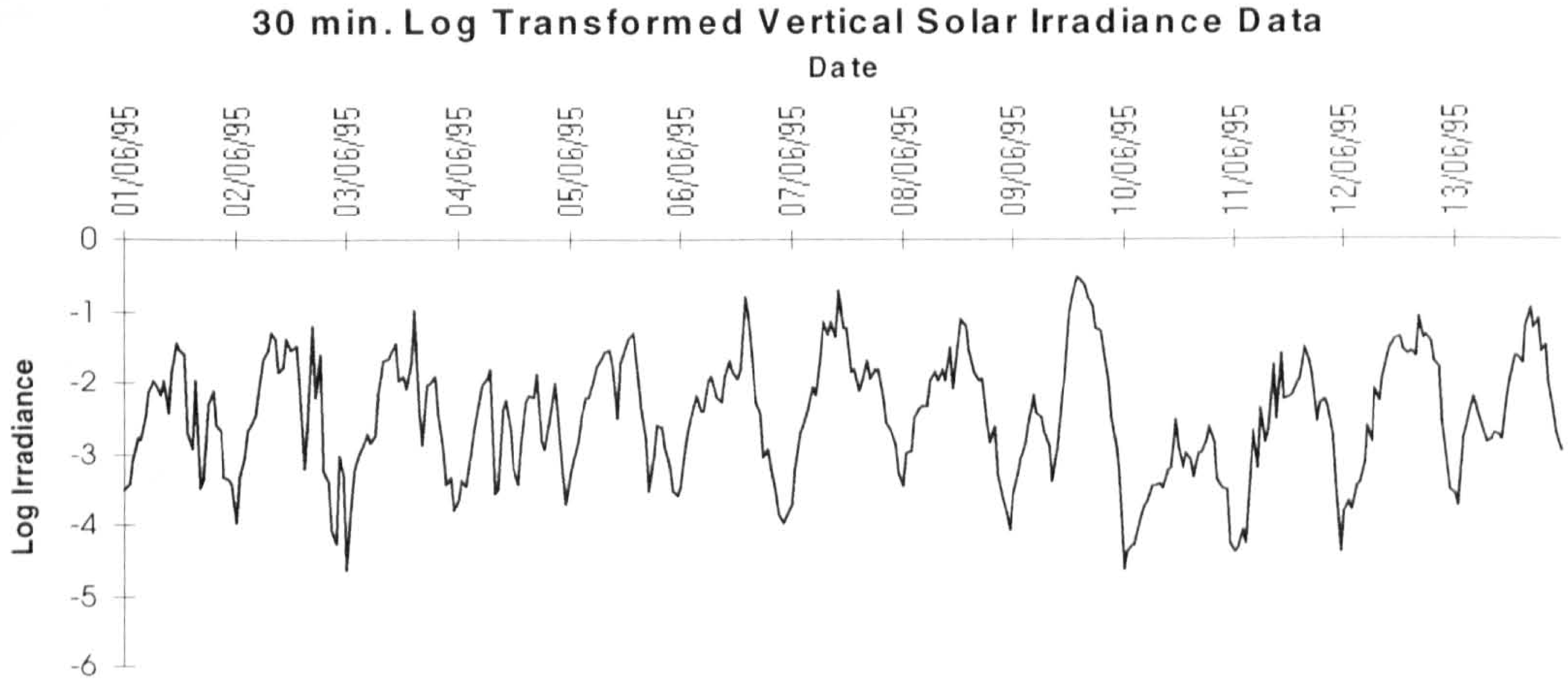
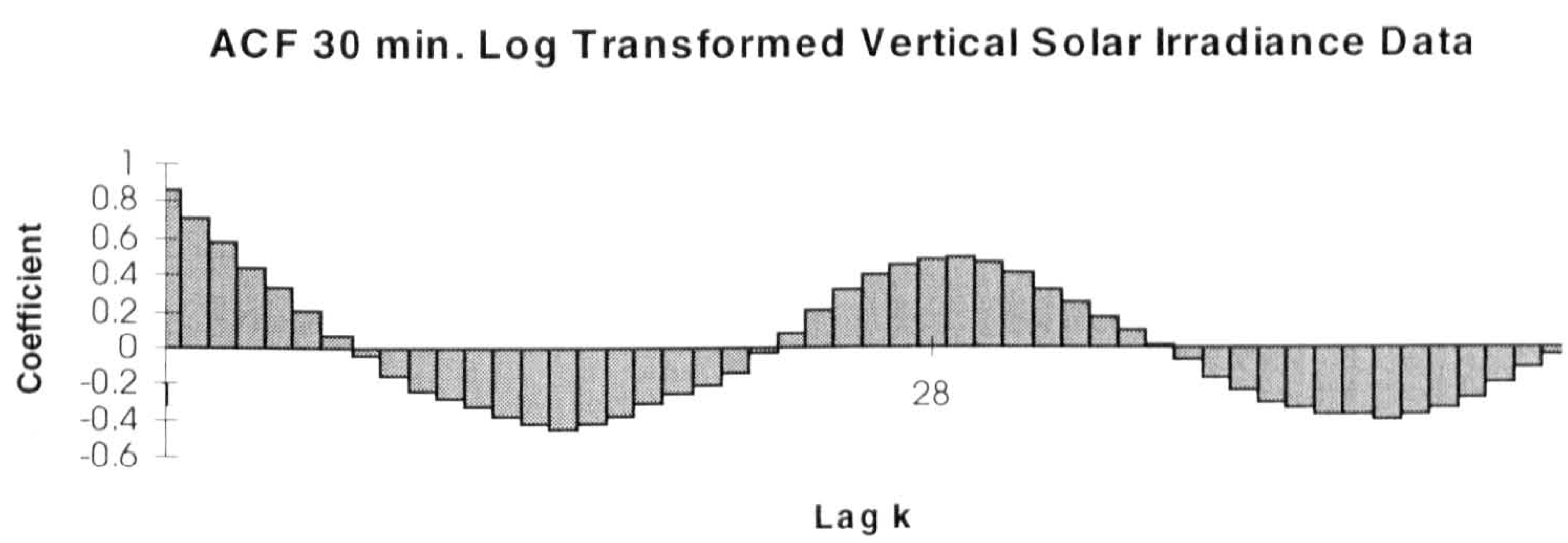


Figure 4.23.4 Log transformed Vertical Solar Irradiance - 30 minute averages, JUN95_30

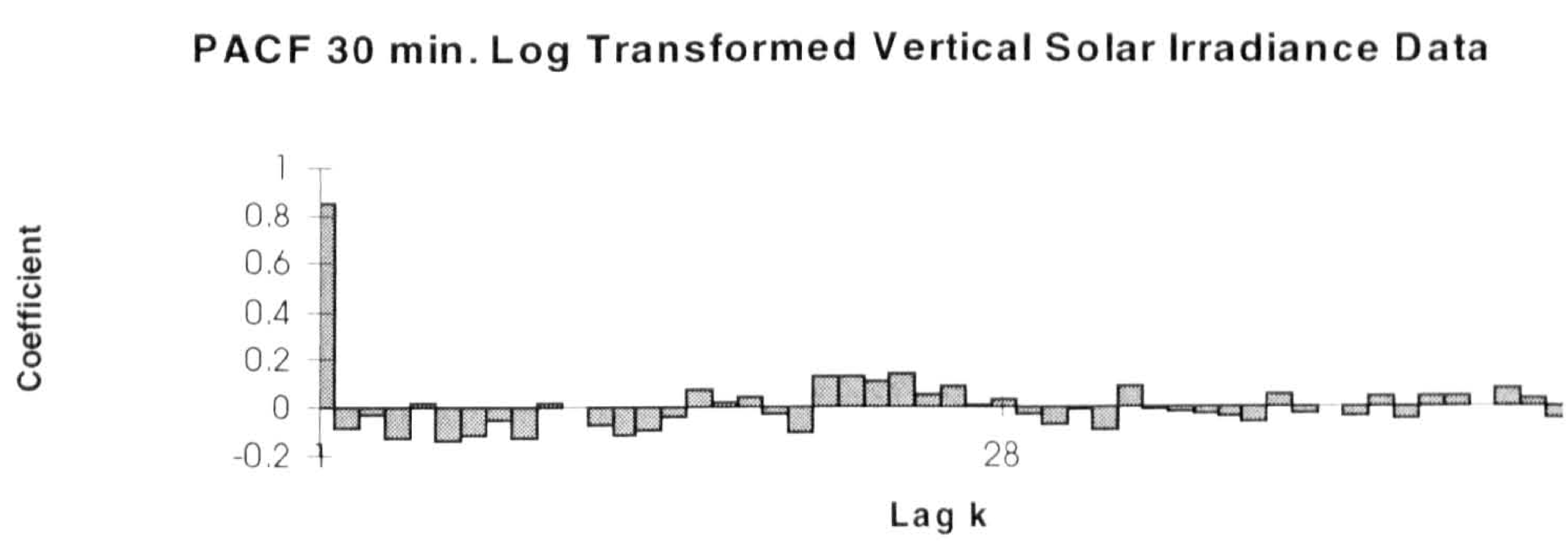
a)



b)



c)



4.24. June 1995 (1st - 13th) - Sixty minute averages

This data set, known as JUN95_60, contains 60 minute averaged Horizontal and Vertical Solar Irradiance data recorded between 1st and 13th June 1995.

4.24.1. Horizontal Solar Irradiance

The time series plot, Figure 4.24.1(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.24.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.24.1(b), and the structure of the ACF and PACF, Figure 4.24.1(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model accounted for 57% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.24.1(b) the ACF and the PACF of the differenced series do not exhibit any structure and an ARIMA model cannot be determined.

4.24.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.24.2(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.24.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.24.2(b), and the structure of the ACF and PACF, Figure 4.24.2(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model accounted for 62% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.24.2(b) an ARIMA(0,1,0)(1,0,0)14 model was fitted to the

data. This model accounted for 56% of the total variance and the ACF of the residuals showed no structure.

4.24.3. Vertical Solar Irradiance

The time series plot, Figure 4.24.3(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.24.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Table 4.24.3(b), and the structure of the ACF and PACF, Figure 4.24.3(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model accounted for 57% of the total variance but the ACF of the residuals is not consistent with a 'white noise' process.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.24.3(b) the ACF and the PACF of the differenced series do not exhibit any structure and an ARIMA model cannot be determined.

4.24.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.24.4(a), displays the daily cyclic nature of the data with 14 observations per day. The ACF of the data, Figure 4.24.4(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 14. From the autocorrelation and partial autocorrelation coefficients, Figure 4.24.4(b), and the structure of the ACF and PACF, Figure 4.24.4(b) & (c), an ARIMA(1,0,0)(1,0,0)14 model was fitted to the data. This model accounted for 65% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.24.4(b) an ARIMA(0,1,0)(1,0,0)14 model was fitted to the

data. This model accounted for 60% of the total variance and the ACF of the residuals showed no structure.

Table 4.24.1 Summary information for Horizontal Solar Irradiance - 60 minute averages (datafile JUN95_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.2274	0.1507	0.0231	0.7956

b)

$2/\sqrt{182} = 0.148$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.745	0.745	0.049	0.049
2	0.469	-0.194	-0.008	-0.010
3	0.200	-0.170	-0.077	-0.076
4	-0.025	-0.119	-0.096	-0.089
14	0.358	0.097	0.140	-0.063

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(3,0,0)(1,0,0)14	AR1	0.8324	0.0743	11.20	1.66320	0.00940	58
	AR2	-0.0386	0.0979	-0.39			
	AR3	-0.1524	0.0771	-1.98			
	SAR14	0.1167	0.0790	1.48			
	CONST	0.07135	0.00719	9.93			
ARIMA(1,0,0)(1,0,0)14	AR1	0.7158	0.0516	13.87	1.73982	0.00972	57
	SAR14	0.2091	0.0750	2.79			
	CONST	0.0508	0.0073	6.95			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.1558	0.0755	2.06	2.01958	0.01122	50

Table 4.24.2 Summary information for Log Transformed Horizontal Solar Irradiance - 60 minute averages (datafile JUN95_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-1.7265	0.7485	-3.7686	-0.2286

b)

$2/\sqrt{182} = 0.148$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.751	0.751	0.102	0.102
2	0.457	-0.247	-0.039	-0.050
3	0.185	-0.141	-0.093	-0.085
4	-0.037	-0.112	-0.098	-0.082
14	0.504	0.09	0.286	0.097

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)(1,0,0)14	AR1	0.815	0.0752	10.83	37.468	0.2105	62
	AR2	-0.1433	0.0753	-1.90			
	SAR14	0.3163	0.0738	4.29			
	CONST	-0.3879	0.03402	-11.40			
ARIMA(1,0,0)(1,0,0)14	AR1	0.7043	0.0530	13.28	38.0950	0.2128	62
	SAR14	0.3703	0.0710	5.21			
	CONST	-0.3215	0.0342	-9.90			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.3196	0.0723	4.42	44.7818	0.2488	55

Table 4.24.3 Summary information for Vertical Solar Irradiance - 60 minute averages (datafile JUN95_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.1172	0.0944	0.0112	0.5857

b)

$2/\sqrt{182} = 0.148$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.749	0.749	0.071	0.071
2	0.465	-0.217	-0.014	-0.019
3	0.194	-0.162	-0.041	-0.039
4	-0.052	-0.165	-0.143	-0.138
14	0.324	0.164	0.124	-0.062

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)14	AR1	0.7338	0.0509	14.42	0.68005	0.003799	57
	SAR14	0.1787	0.0764	2.34			
	CONST	0.0251	0.0045	5.49			
ARIMA(2,0,0)(1,0,0)14	AR1	0.8833	0.0736	12.00	0.65614	0.003686	58
	AR2	-0.1949	0.0736	-2.65			
	SAR14	0.1290	0.0768	1.68			
	CONST	0.03139	0.00450	6.97			

Table 4.24.4 Summary information for Log Transformed Vertical Solar Irradiance - 60 minute averages (datafile JUN95_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-2.4479	0.8099	-4.4948	-0.5350

b)

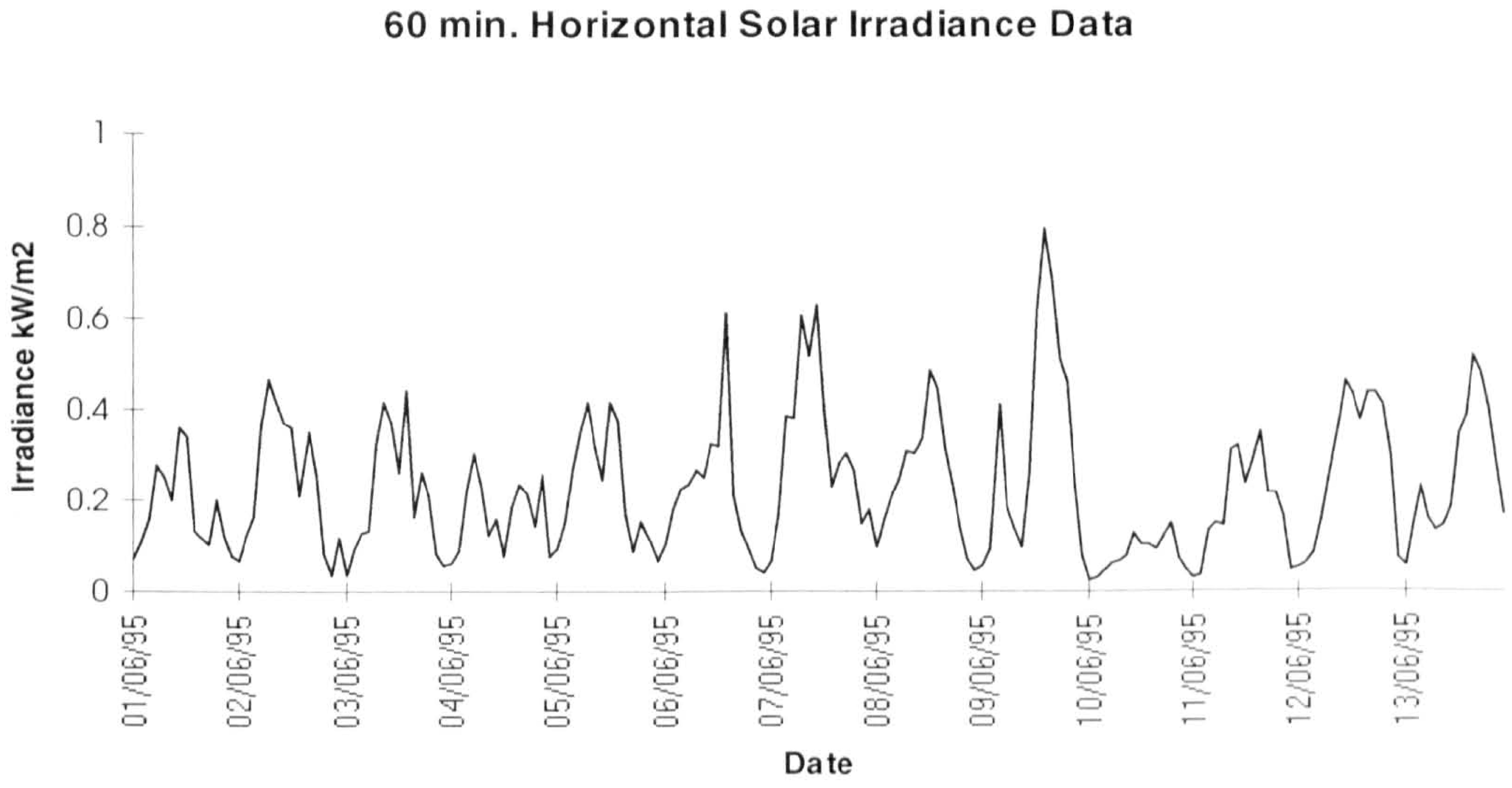
$2/\sqrt{182} = 0.148$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.772	0.772	0.142	0.142
2	0.487	-0.270	-0.018	-0.039
3	0.215	-0.145	-0.014	-0.006
4	-0.045	-0.200	-0.124	-0.125
14	0.524	0.104	0.298	0.155

c)

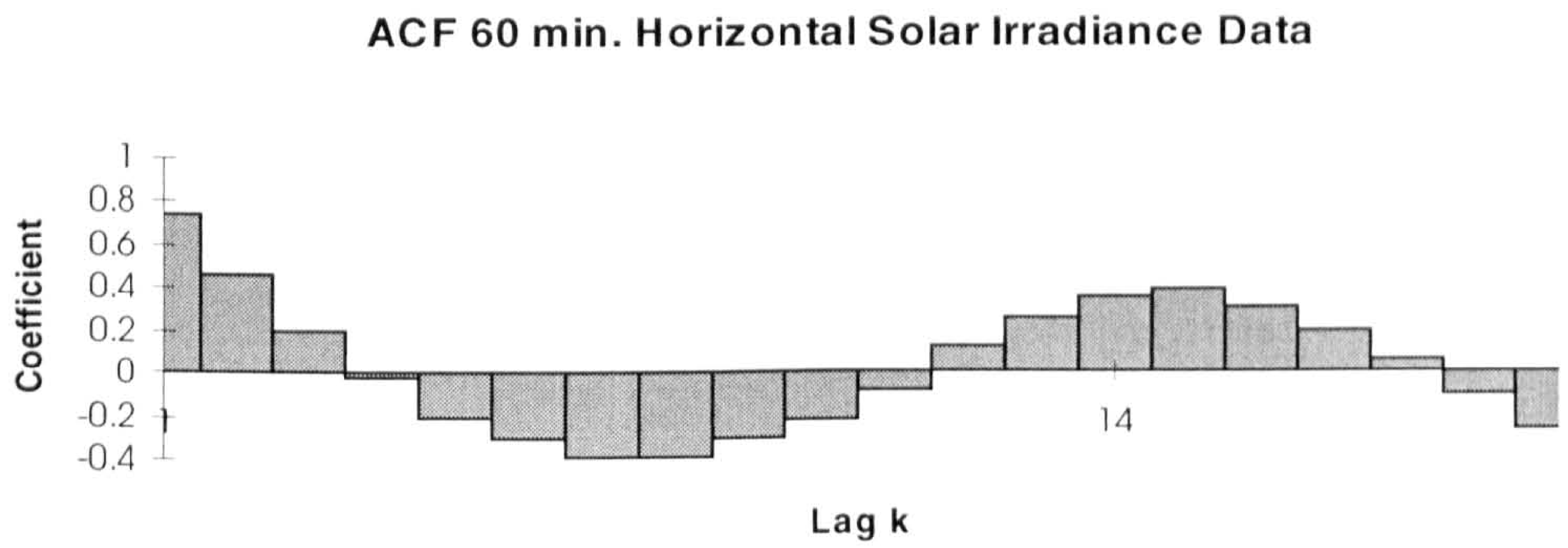
model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)14	AR1	0.7248	0.0514	14.11	40.6636	0.2272	65
	SAR14	0.3900	0.0709	5.50			
	CONST	-0.4118	0.0363	-11.65			
ARIMA(0,1,0)(1,0,0)14	SAR14	0.3400	0.0723	4.70	47.2751	0.2626	60

Figure 4.24.1 Horizontal Solar Irradiance - 60 minute averages, JUN95_60

a)



b)



c)

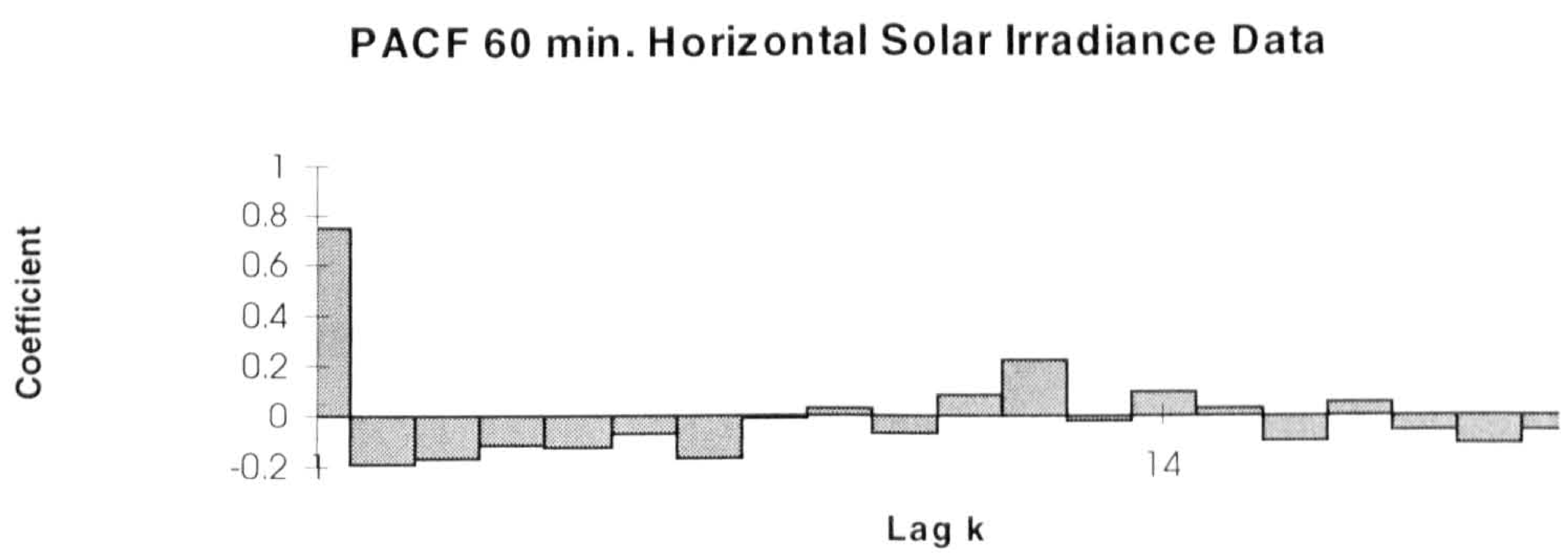
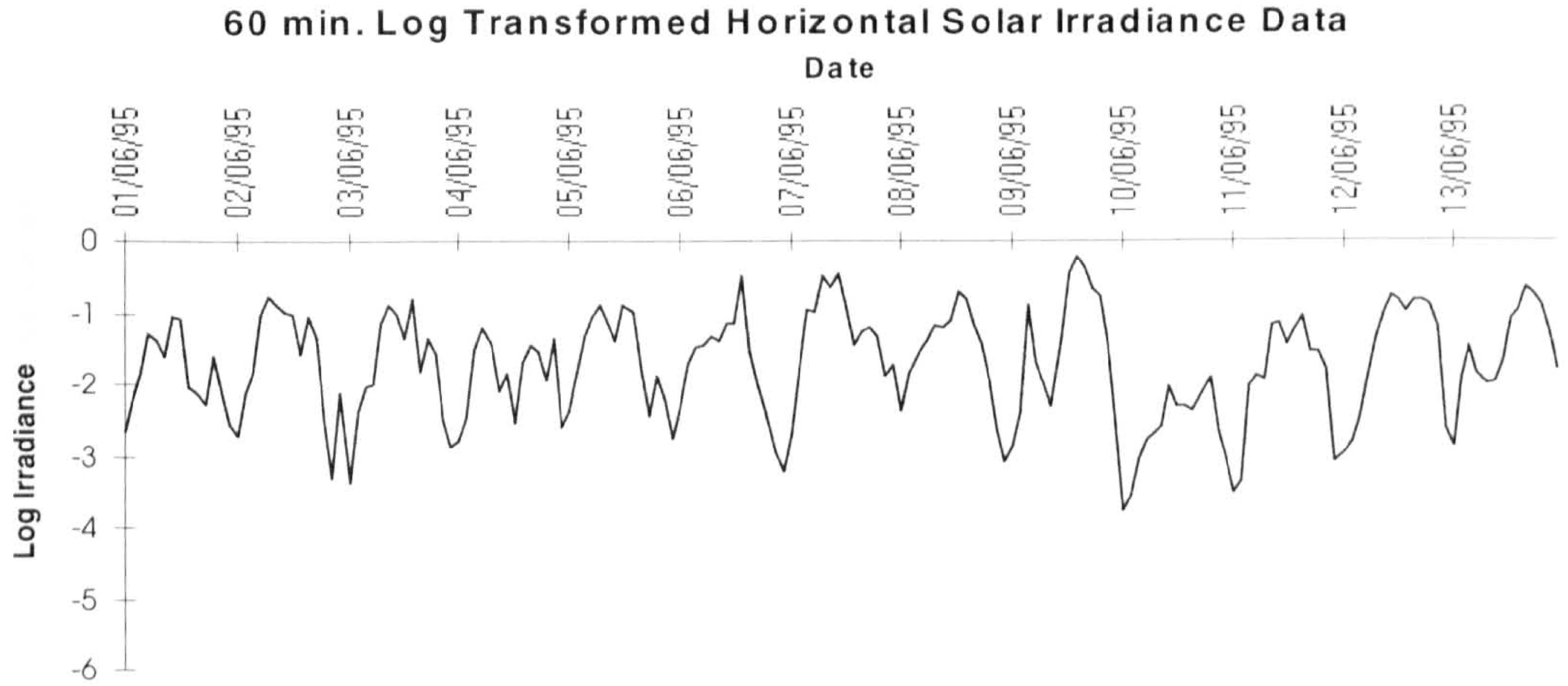
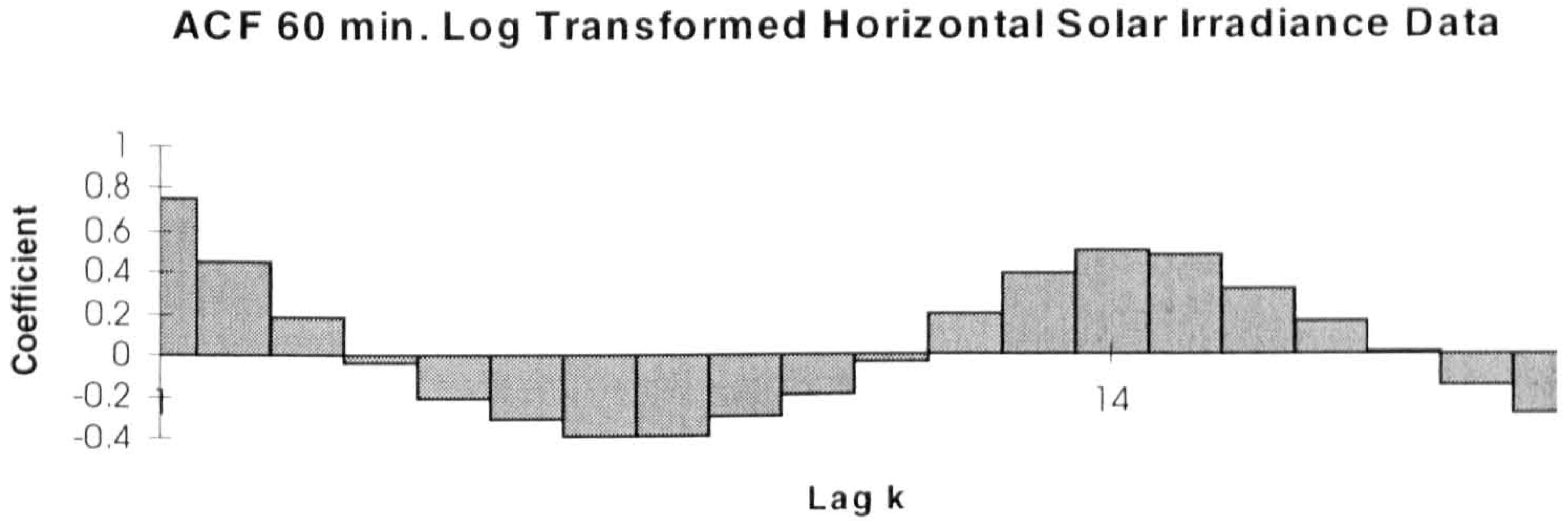


Figure 4.24.2 Log transformed Horizontal Solar Irradiance - 60 minute averages, JUN95_60

a)



b)



c)

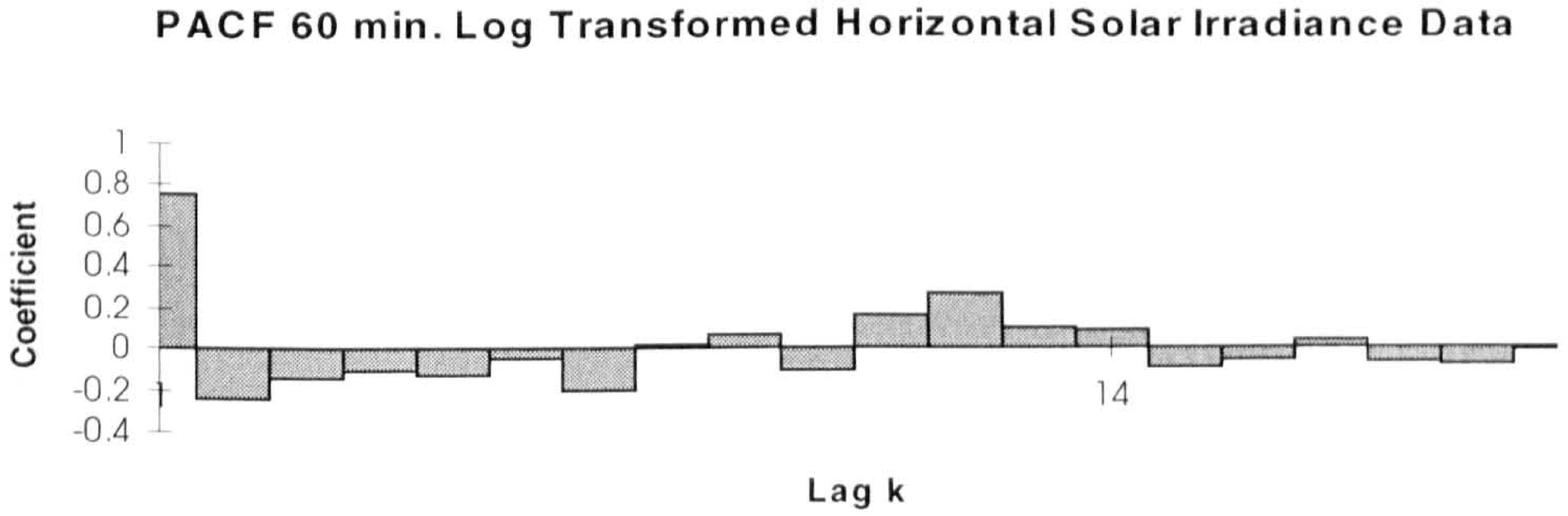
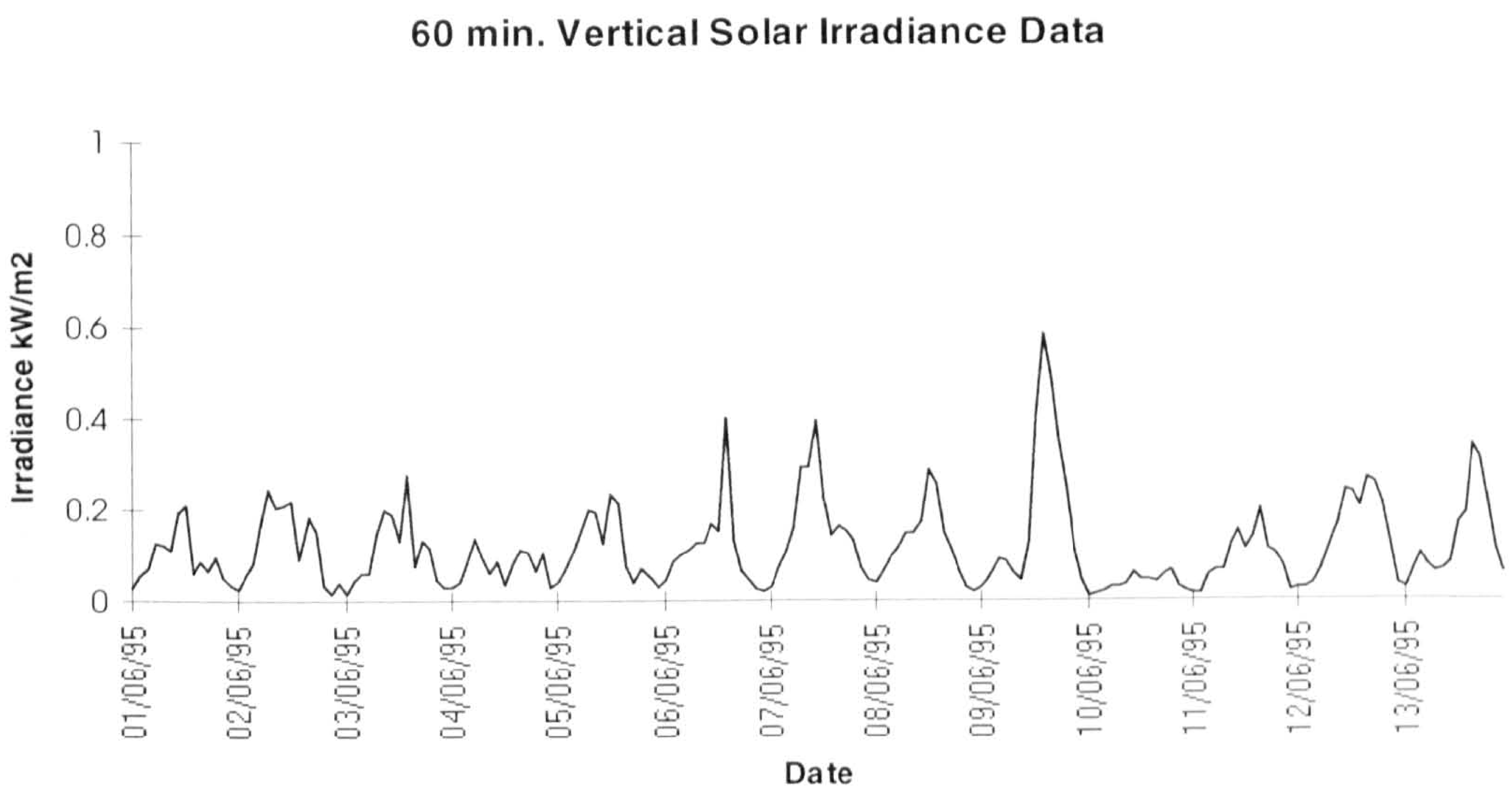
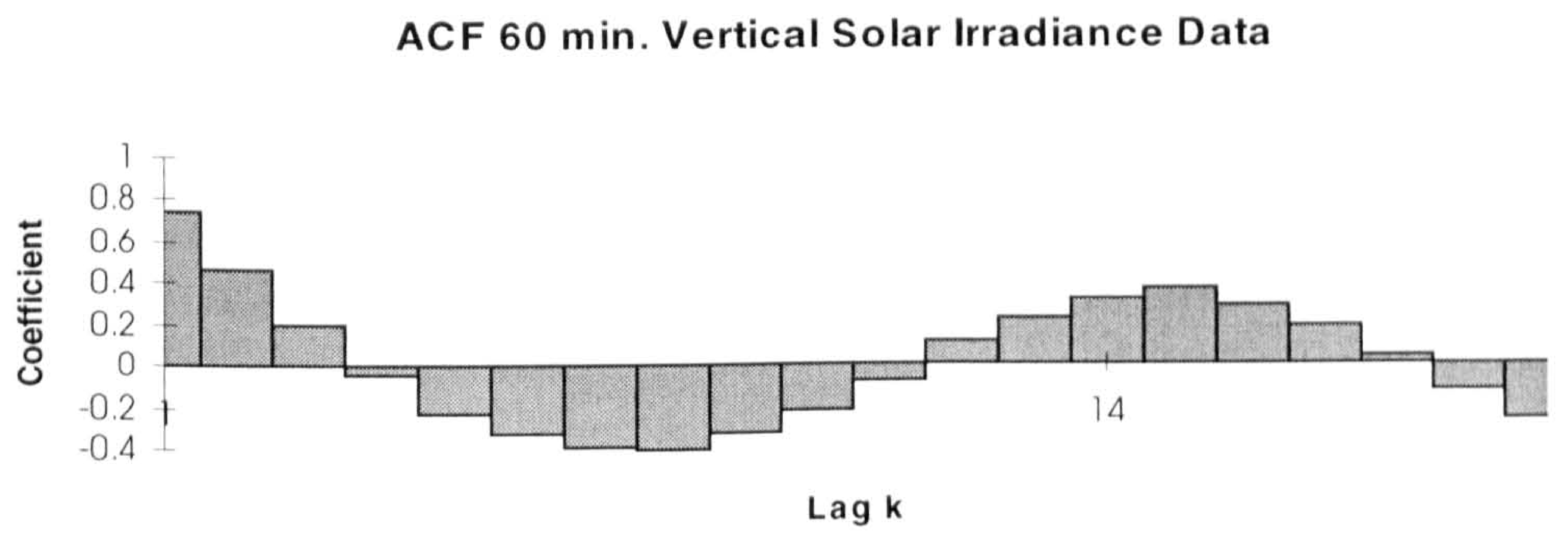


Figure 4.24.3 Vertical Solar Irradiance - 60 minute averages, JUN95_60

a)



b)



c)

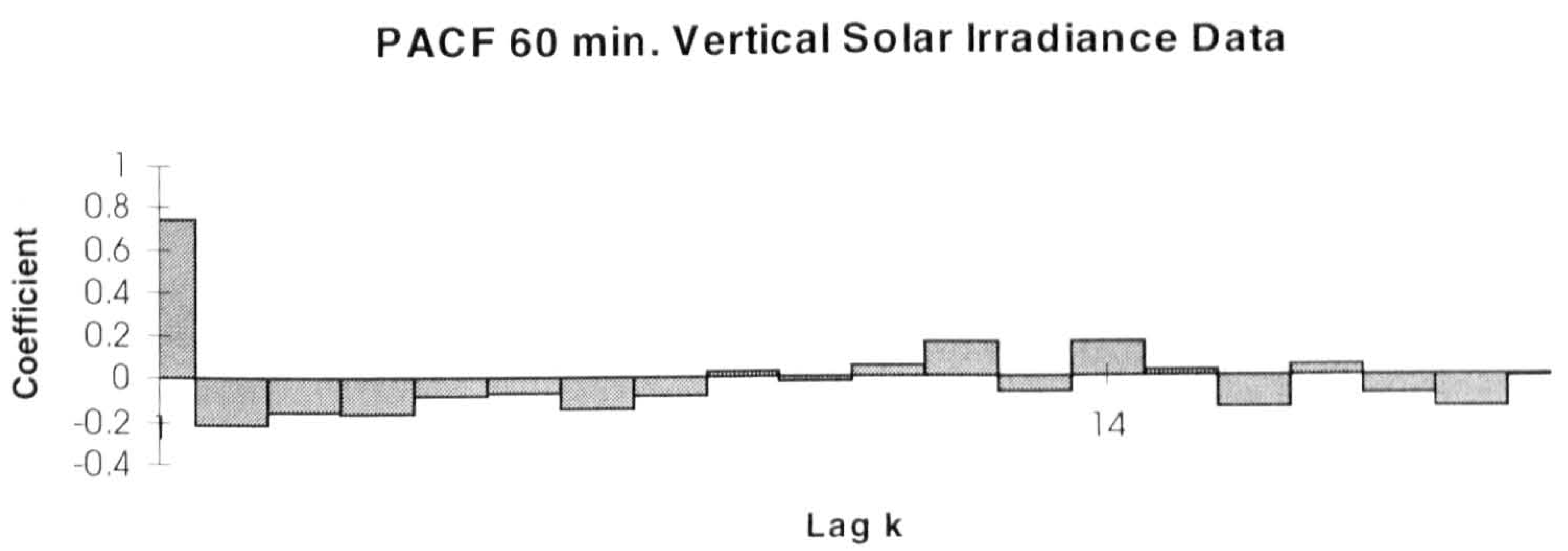
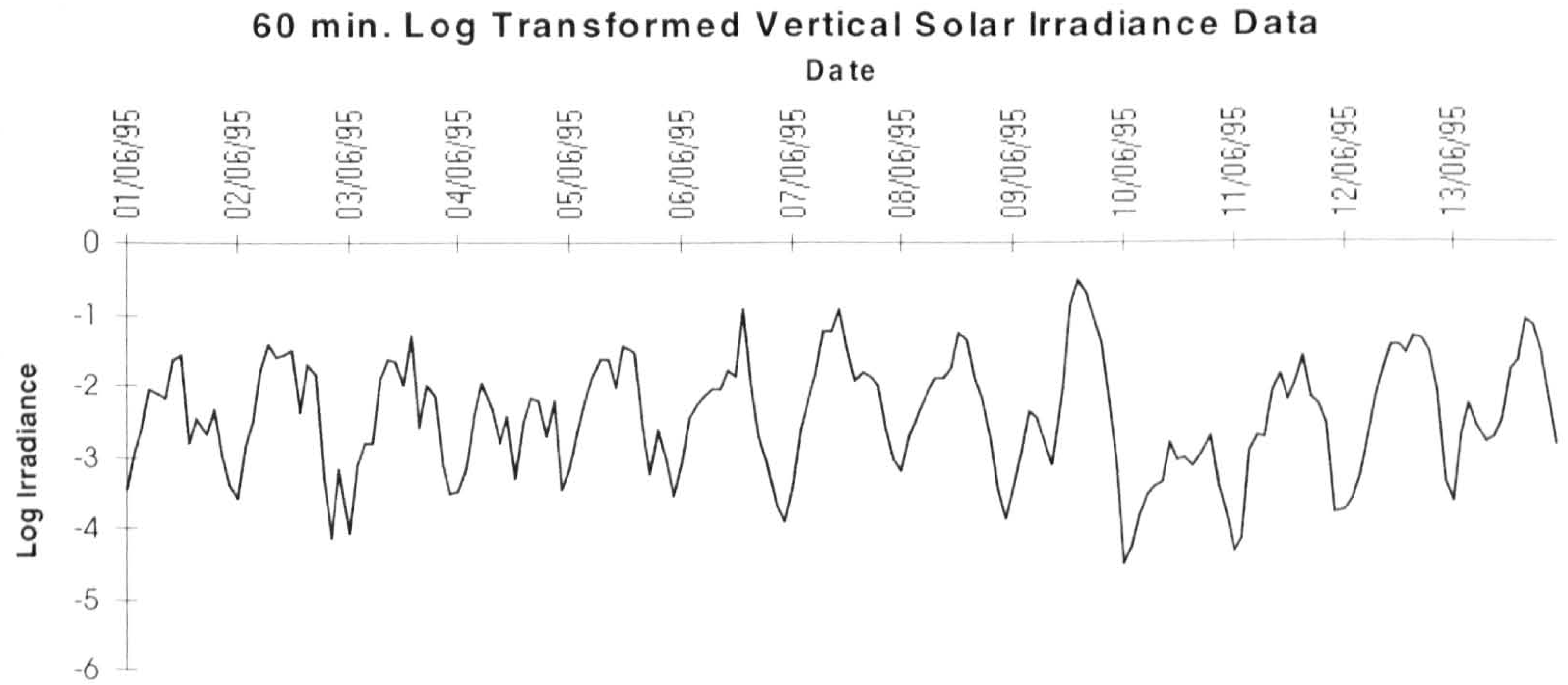
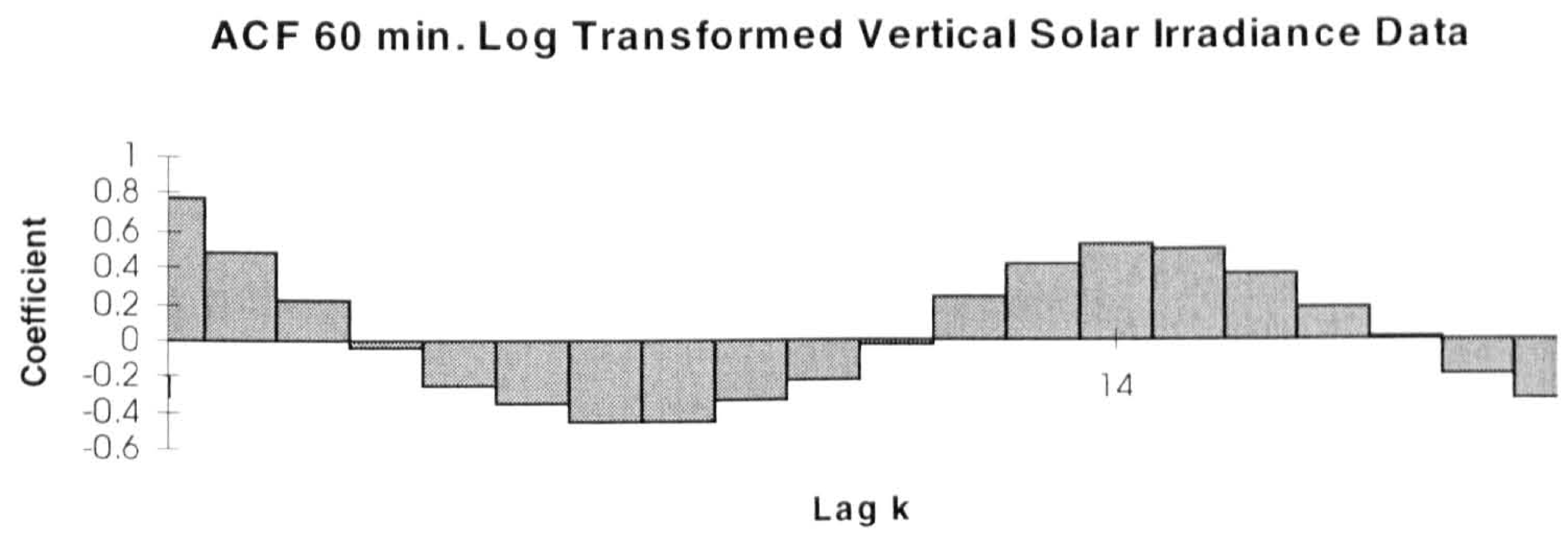


Figure 4.24.4 Log transformed Vertical Solar Irradiance - 60 minute averages, JUN95_60

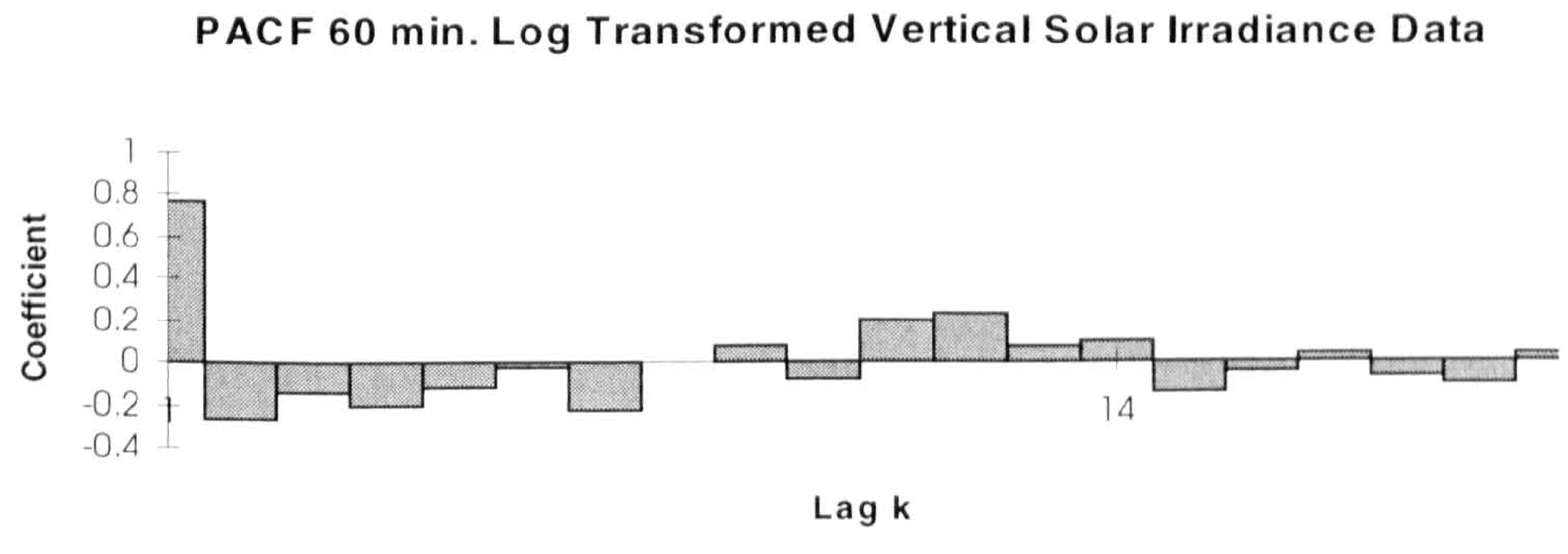
a)



b)



c)



4.25. December 1995 - Ten minute averages

This data set, known as DEC95_10, contains 10 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 7th and 19th December 1995.

4.25.1. Horizontal Solar Irradiance

The time series plot, Figure 4.25.1(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.25.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36 which represents the daily lag. From the autocorrelation and partial autocorrelation coefficients, Table 4.25.1(b),and the structure of the ACF and PACF, Figure 4.25.1(b) & (c), an ARIMA(1,0,0)(1,0,0)36 model was fitted to the data. This model was found to be appropriate, accounted for 79% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.25.1(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

4.25.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.25.2(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.25.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.25.2(b) and the structure of the ACF and PACF, Figure 4.25.2(b) & (c), an ARIMA(1,0,0)(1,0,0)36 model was fitted to the data. This model was found to be appropriate, accounted for 82% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.25.2(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

4.25.3. Vertical Solar Irradiance

The time series plot, Figure 4.25.3(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.25.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.25.3(b) and the structure of the ACF and PACF, Figure 4.25.3(b) & (c), an ARIMA(1,0,0)(1,0,0)36 model was fitted to the data. This model was found to be appropriate, accounted for 78% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.25.3(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

4.25.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.25.4(a), displays the daily cyclic nature of the data with 36 observations per day. The ACF of the data, Figure 4.25.4(b) also emphasises the periodic nature of the data with damped oscillations repeating at lag 36. From the autocorrelation and partial autocorrelation coefficients, Table 4.25.4(b) and the structure of the ACF and PACF, Figure 4.25.4(b) & (c), an ARIMA(1,0,0)(1,0,0)36 model was fitted to the data. This model was found to be appropriate, accounted for 81% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.25.4(b) there is no structure to the ACF and PACF of the first differenced data and a model cannot be determined.

Table 4.25.1 Summary information for Horizontal Solar Irradiance - 10 minute averages (datafile DEC95_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0572	0.0411	0.0051	0.2623

b)

$2/\sqrt{468}=0.092$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.888	0.888	0.016	0.016
2	0.773	-0.075	0.019	0.019
3	0.653	-0.082	-0.142	-0.143
4	0.565	0.075	0.019	0.023
36	0.318	0.043	0.081	0.003

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8922	0.0211	42.24	0.16409	0.000352	79
	CONST	0.0060	0.0008	6.92			
ARIMA(1,0,0)(1,0,0)36	AR1	0.8842	0.218	40.64	0.16240	0.000349	79
	SAR36	0.1040	0.0468	2.22			
	CONST	0.0058	0.0008	6.72			

Table 4.25.2 Summary information for Log Transformed Horizontal Solar Irradiance - 10 minute averages (datafile DEC95_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0977	0.7009	-5.2726	-1.3384

b)

$2/\sqrt{468}=0.092$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.899	0.899	0.056	0.056
2	0.788	-0.100	0.009	0.006
3	0.679	-0.055	-0.079	-0.080
4	0.583	0.003	-0.004	0.005
36	0.454	-0.016	0.128	0.087

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)	AR1	0.9113	0.0198	46.11	41.4536	0.0890	82
	CONST	-0.2792	0.01383	-20.19			
ARIMA(1,0,0)(1,0,0)36	AR1	0.8925	0.0213	41.96	40.0917	0.0862	82
	SAR36	0.2001	0.0469	4.26			
	CONST	-0.2707	0.0136	-19.90			

Table 4.25.3 Summary information for Vertical Solar Irradiance - 10 minute averages (datafile DEC95_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0975	0.1471	0.0032	0.7789

b)

2/√468=0.092	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.883	0.883	-0.058	-0.058
2	0.779	-0.002	0.089	0.086
3	0.655	-0.149	-0.084	-0.076
4	0.550	0.005	-0.040	-0.057
36	0.173	0.065	0.042	-0.010

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)	AR1	0.8842	0.0217	40.76	2.21643	0.00476	78
	CONST	0.0109	0.0032	3.44			
ARIMA(1,0,0)(1,0,0)36	AR1	0.8826	0.0219	40.38	2.21077	0.00475	78
	SAR36	0.0514	0.0464	1.11			
	CONST	0.0105	0.0032	3.29			

Table 4.25.4 Summary information for Log Transformed Vertical Solar Irradiance - 10 minute averages (datafile DEC95_10) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.1950	1.2711	-5.7604	-0.2498

b)

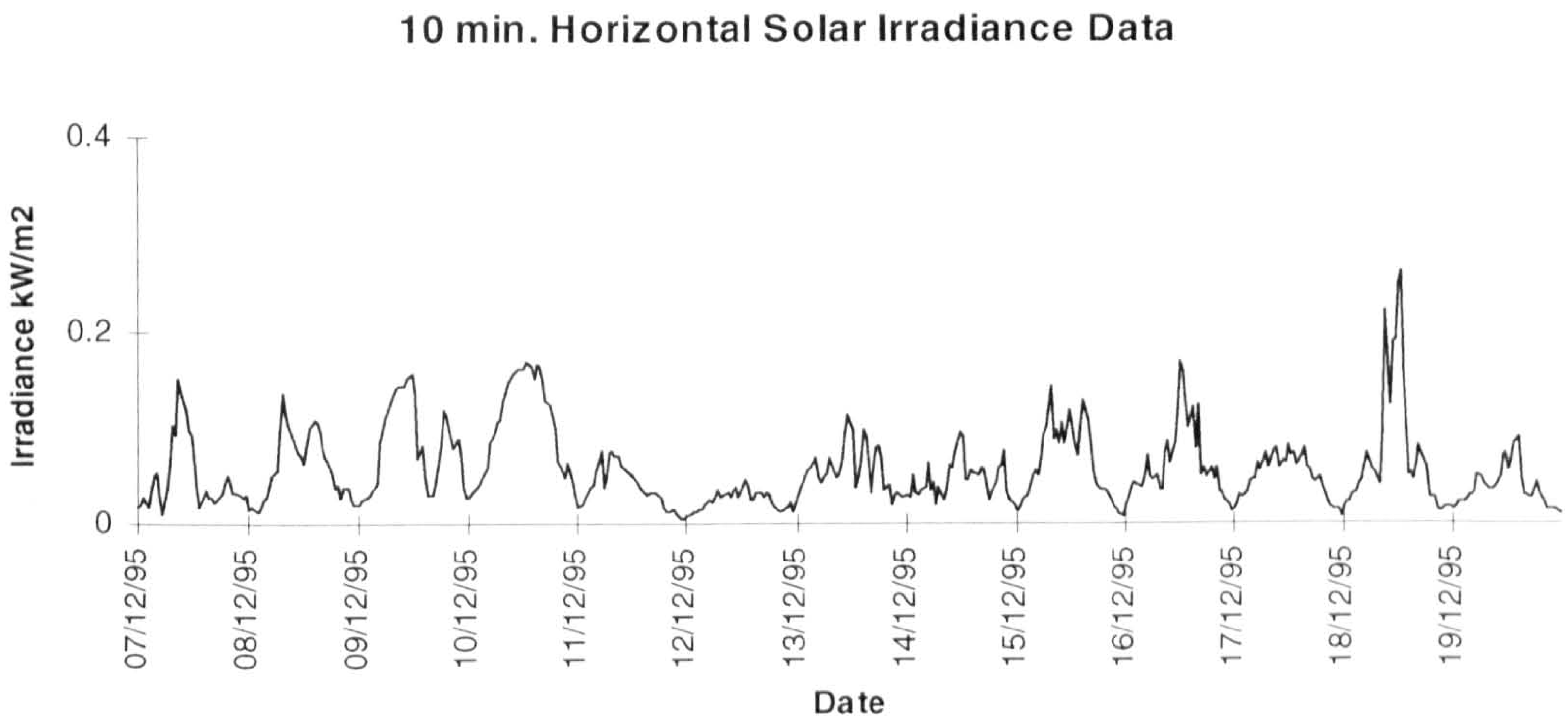
$2/\sqrt{468}=0.092$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.898	0.898	0.035	0.035
2	0.790	-0.086	0.025	0.023
3	0.678	-0.078	-0.091	-0.093
4	0.583	0.022	-0.019	-0.013
36	0.276	0.065	0.062	0.054

c)

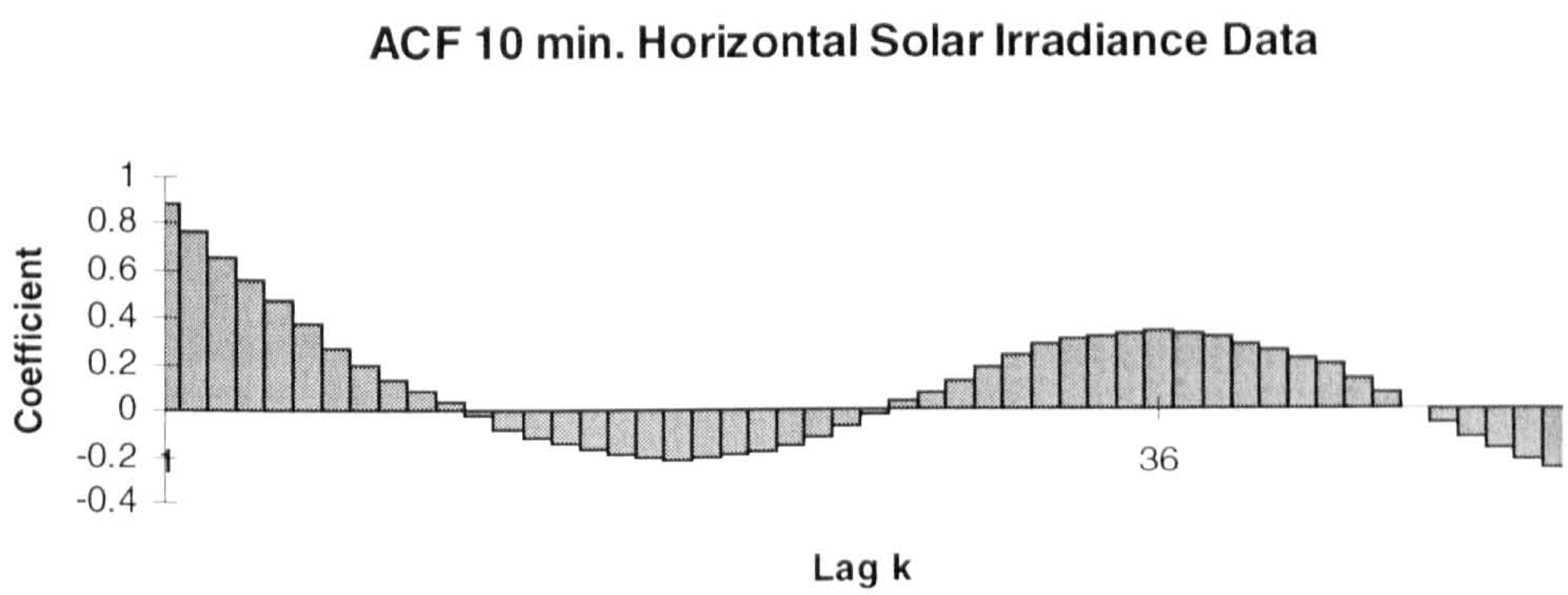
model	parameter	estimate	std. dev.	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)	AR1	0.9052	0.0201	45.13	140.949	0.302	81
	CONST	-0.3092	0.0254	-12.15			
ARIMA(1,0,0)(1,0,0)36	AR1	0.9007	0.0205	44.01	140.008	0.301	81
	SAR36	0.0873	0.0469	1.86			
	CONST	-0.2958	0.0254	-11.65			

Figure 4.25.1 Horizontal Solar Irradiance - 10 minute averages, DEC95_10

a)



b)



c)

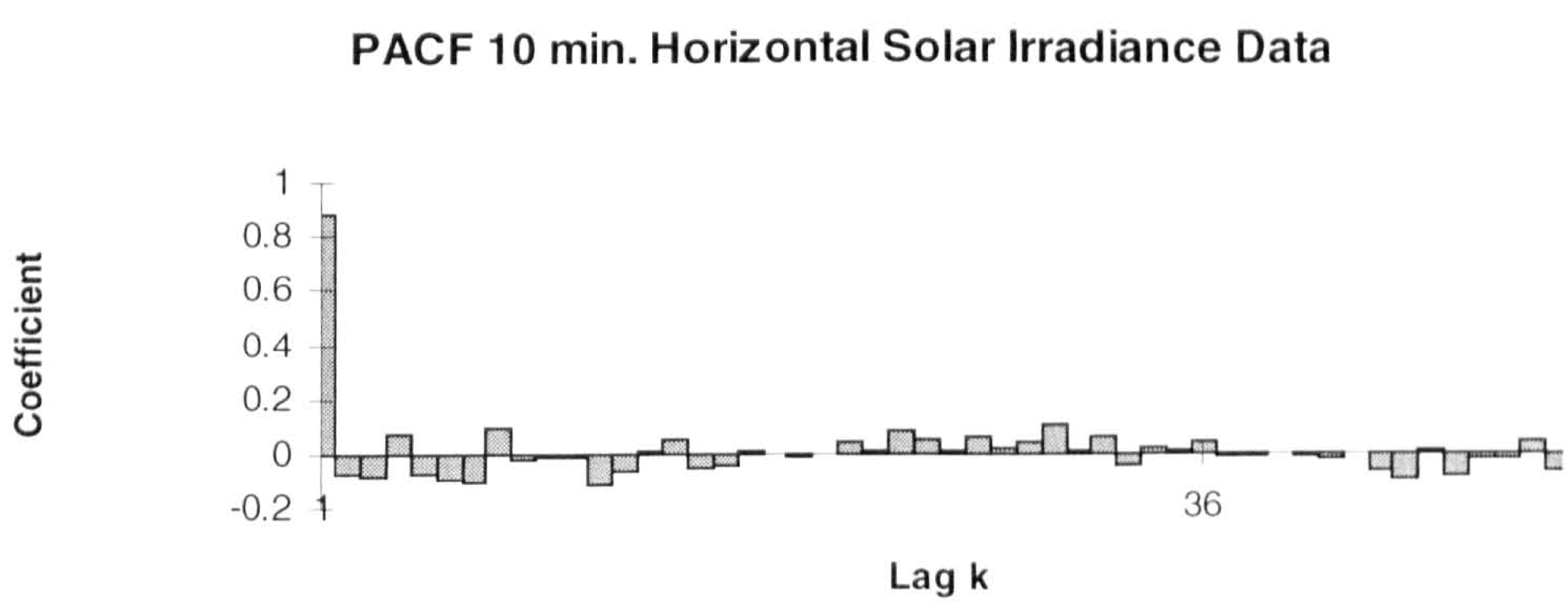
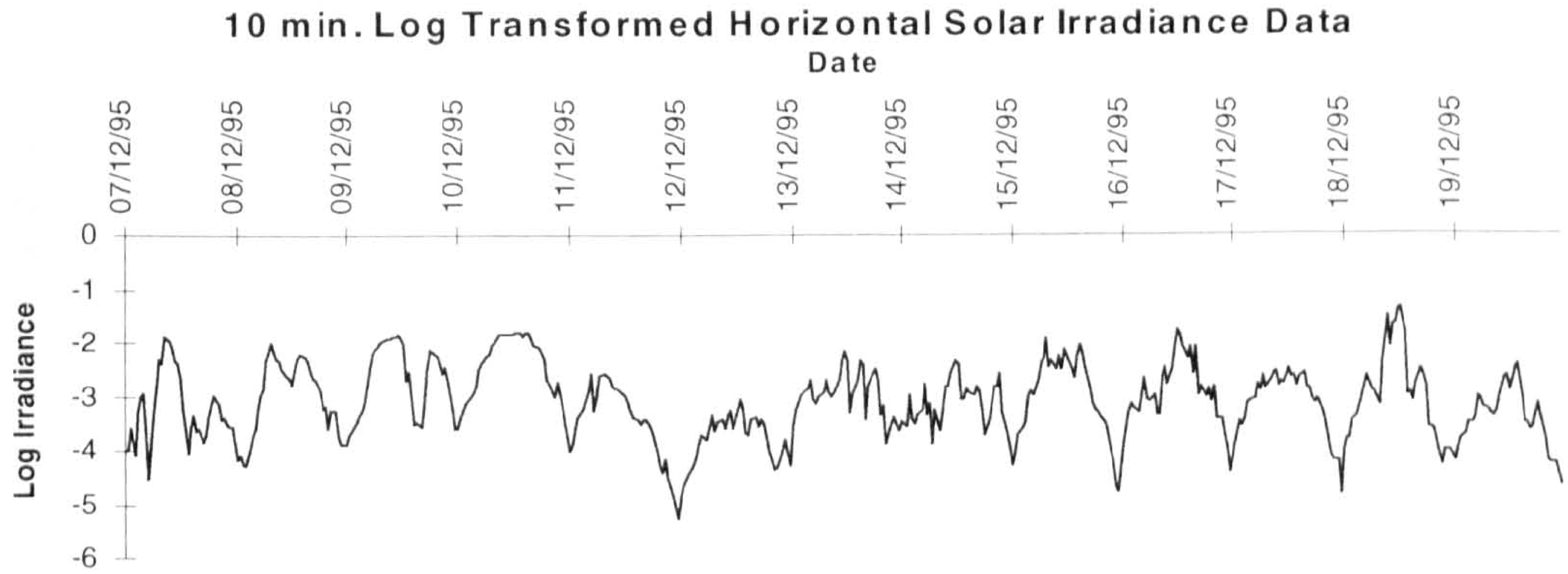
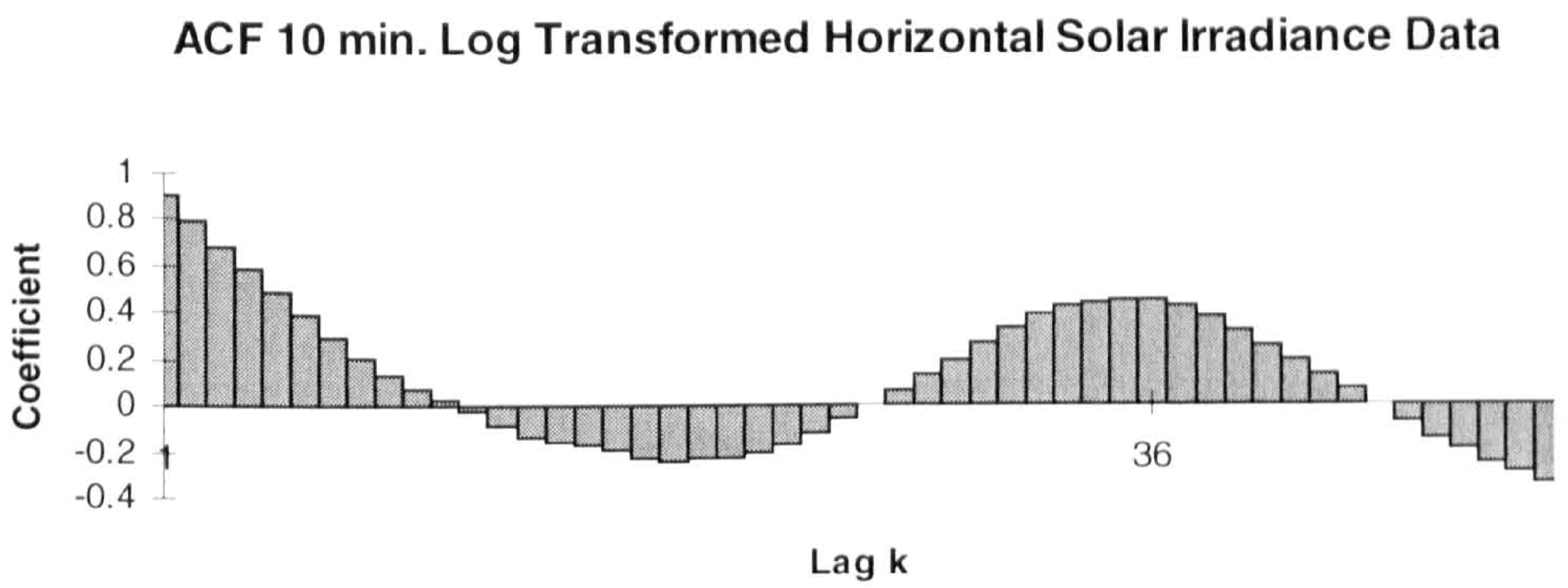


Figure 4.25.2 Log transformed Horizontal Solar Irradiance - 10 minute averages, DEC95_10

a)



b)



c)

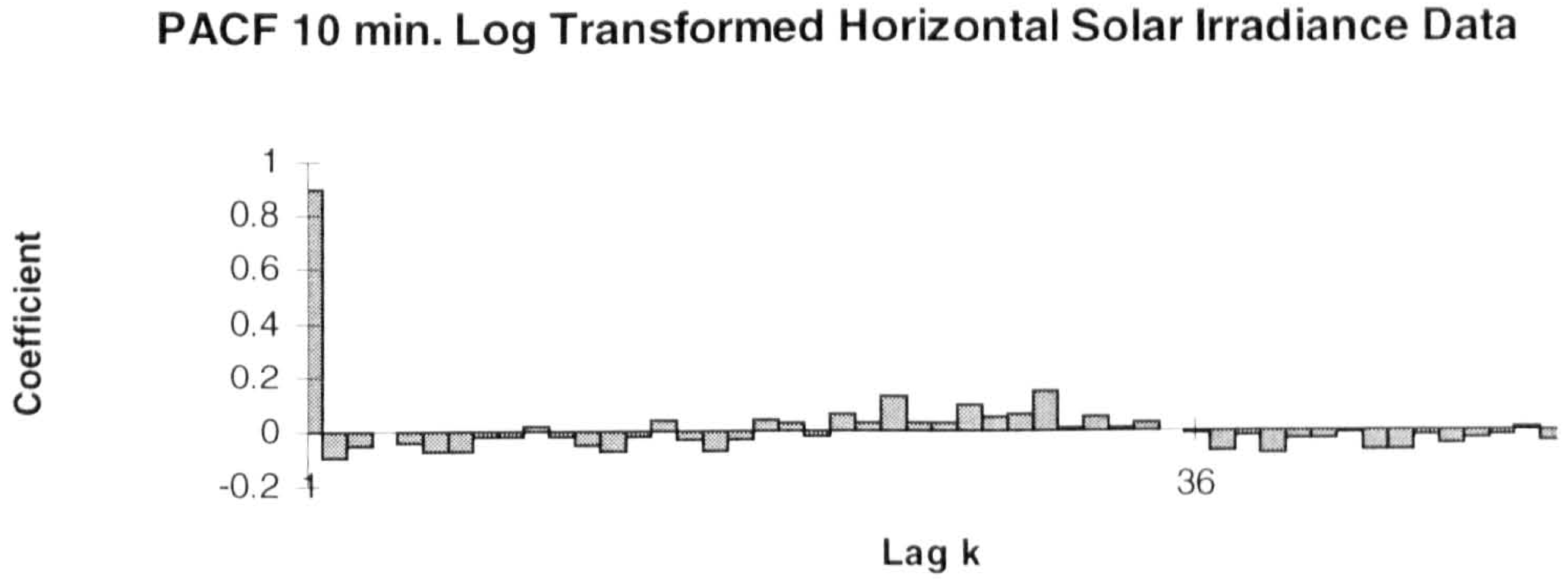
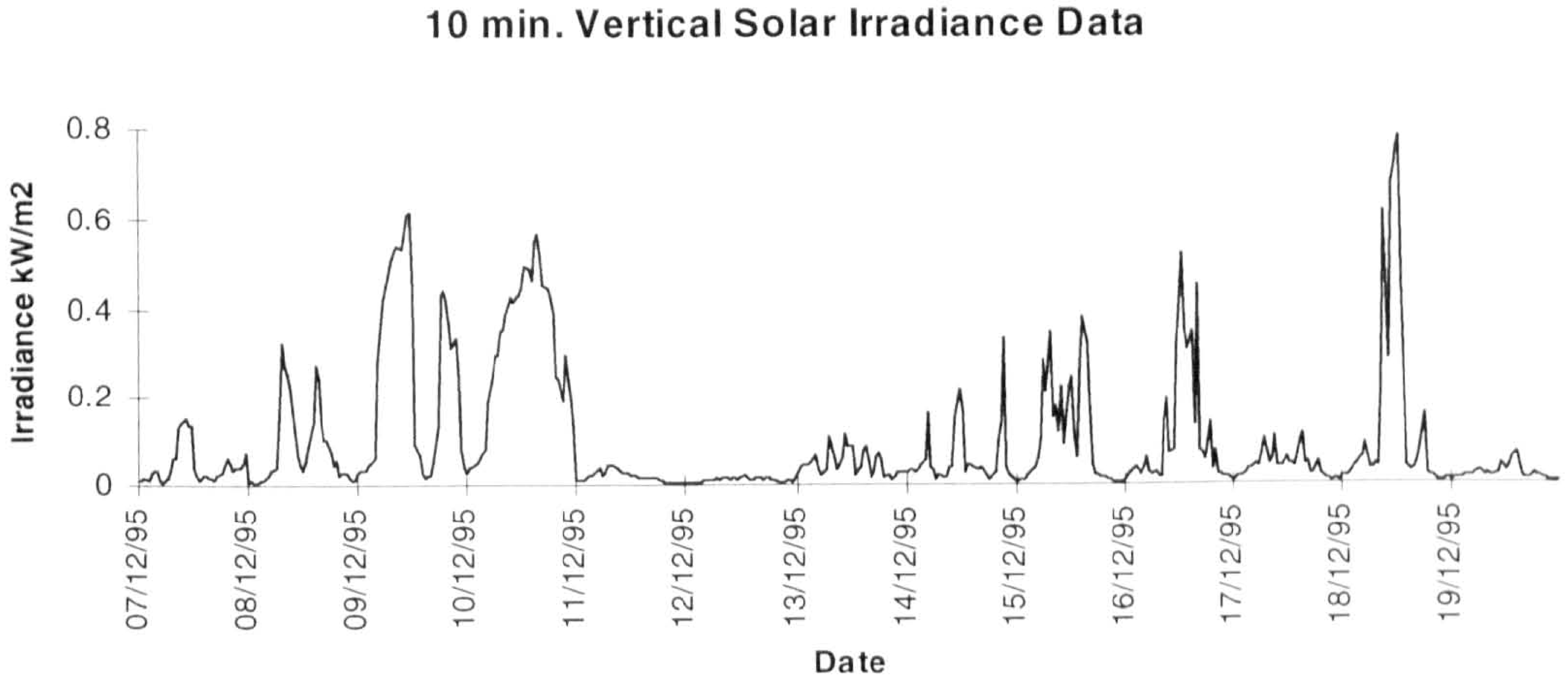
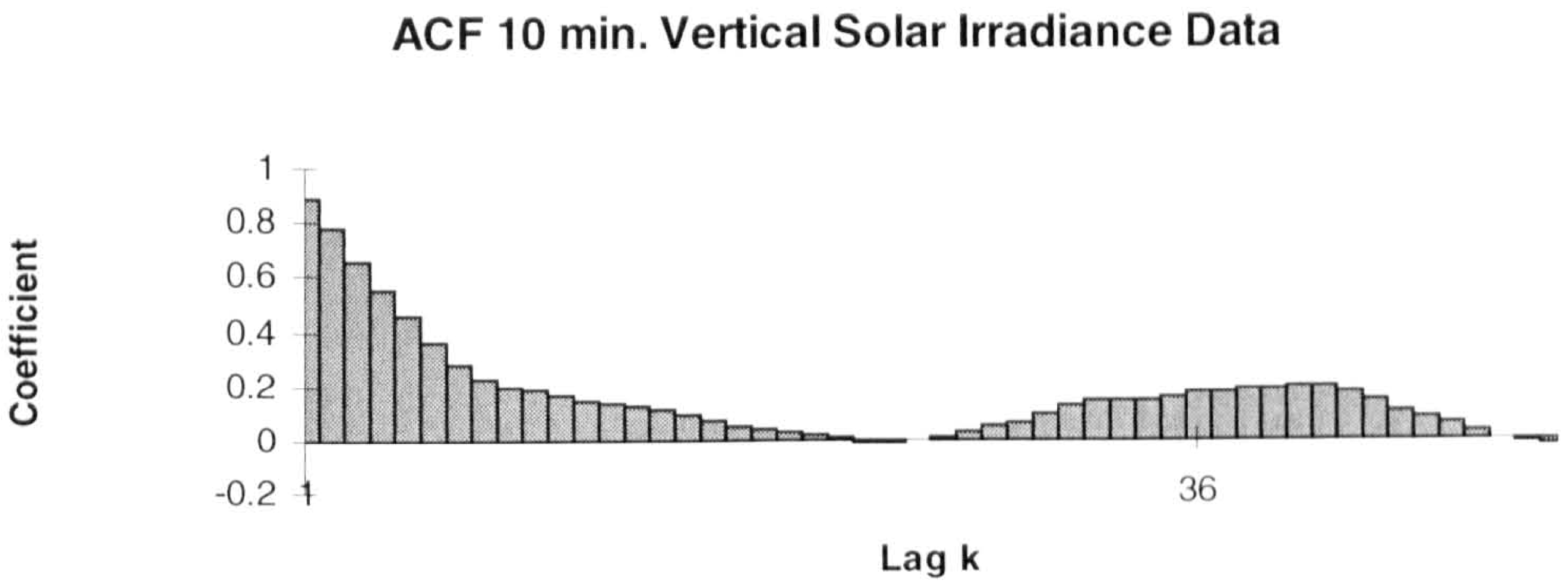


Figure 4.25.3 Vertical Solar Irradiance - 10 minute averages, DEC95_10

a)



b)



c)

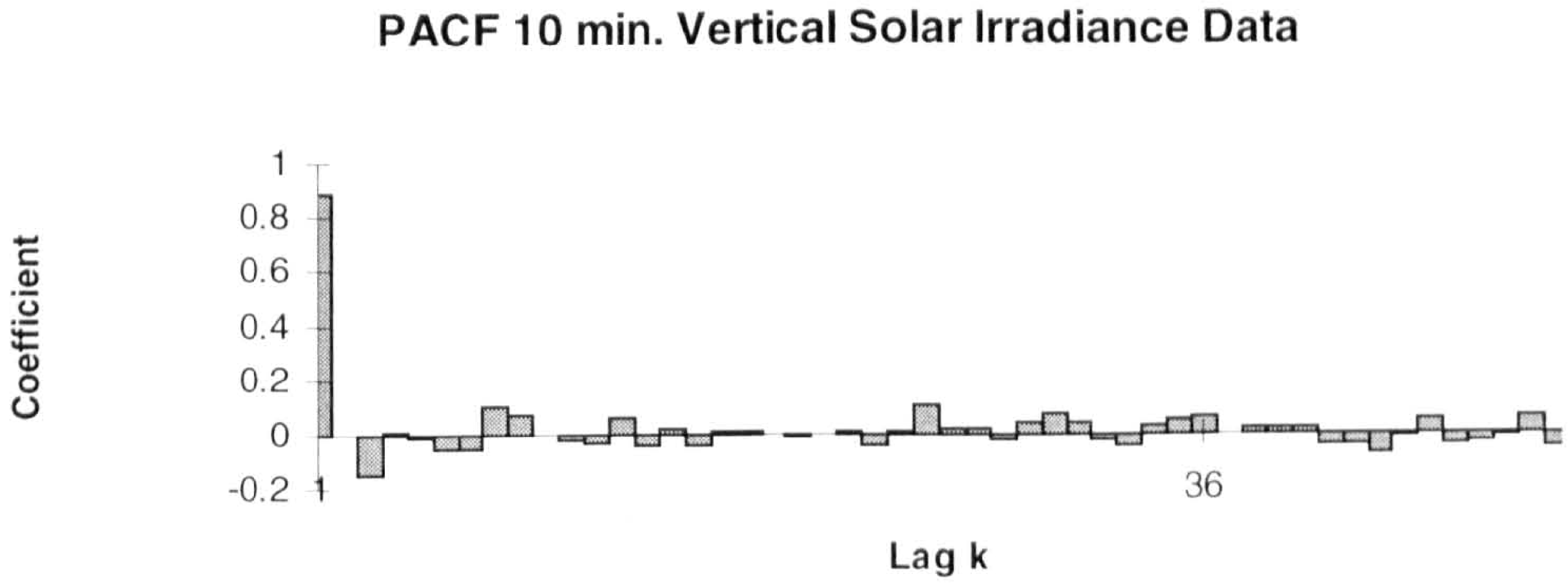
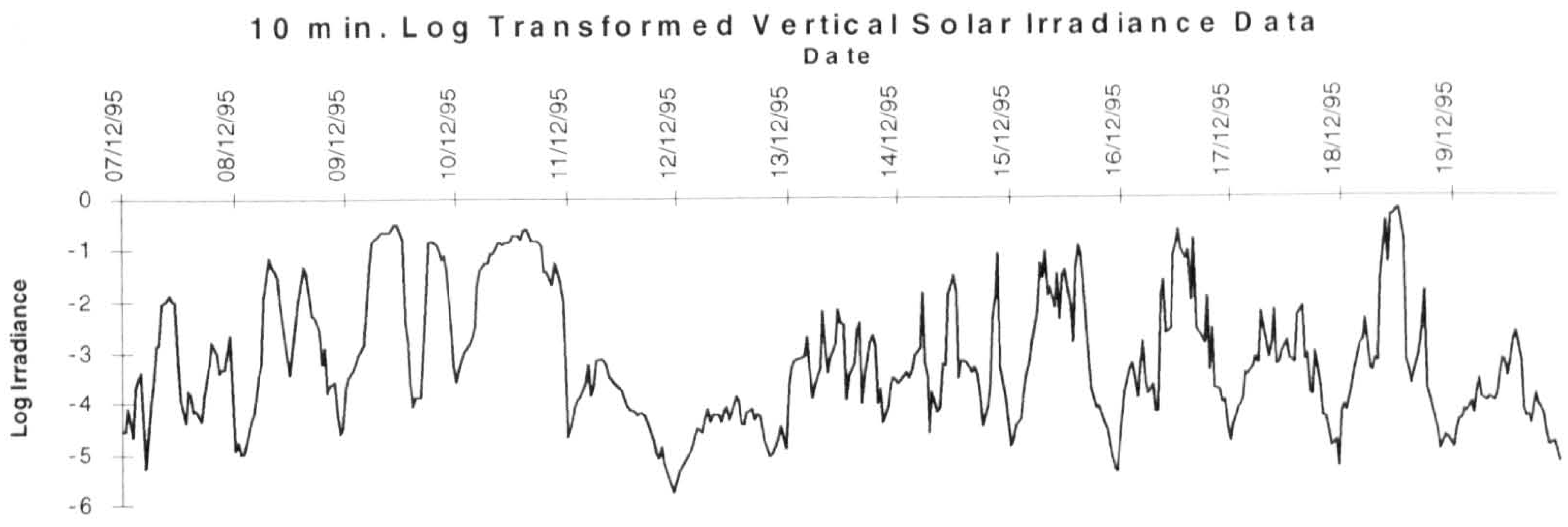
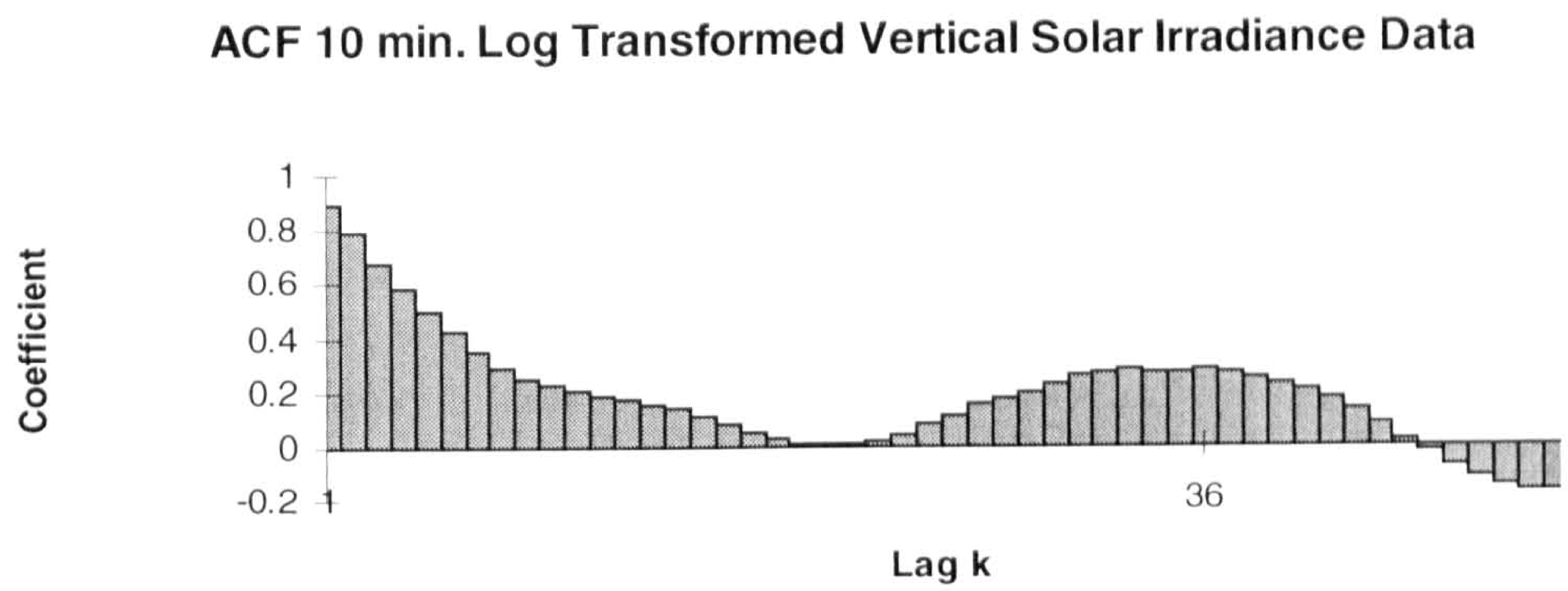


Figure 4.25.4 Log transformed Vertical Solar Irradiance - 10 minute averages, DEC95_10

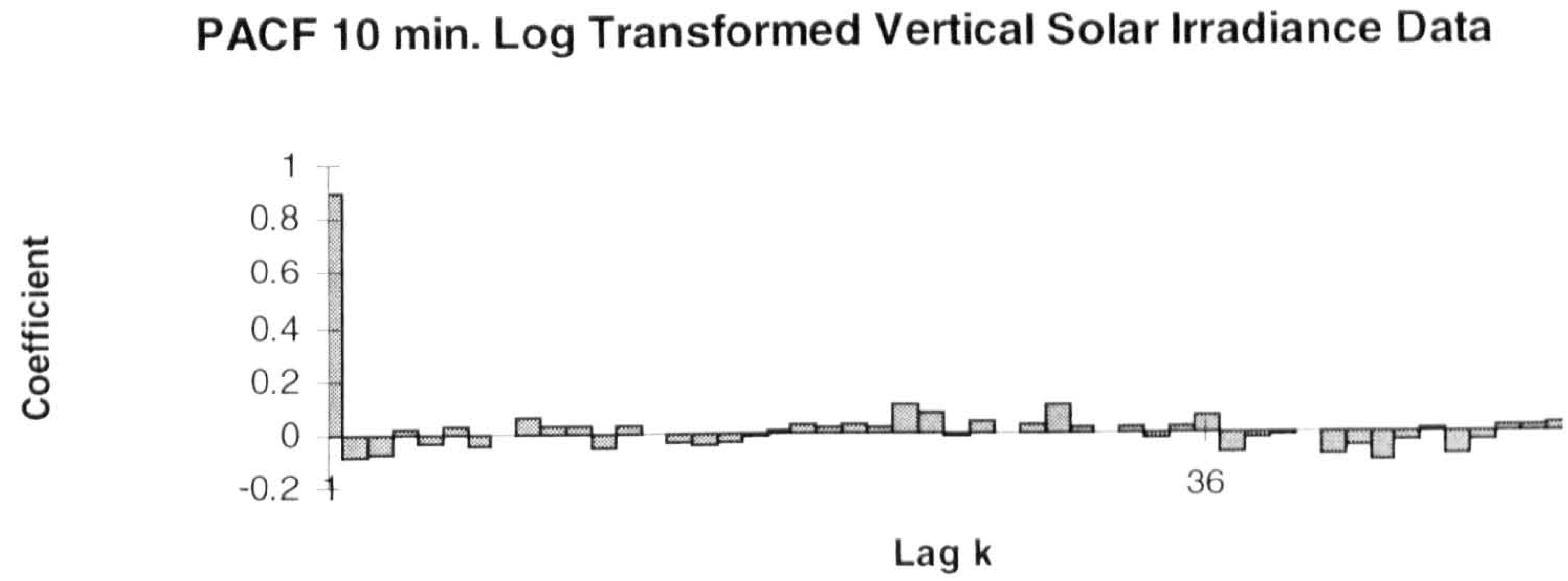
a)



b)



c)



4.26. December 1995 - Twenty minute averages

This data set, known as DEC95_20, contains 20 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 7th and 19th December 1995.

4.26.1. Horizontal Solar Irradiance

The time series plot, Figure 4.26.1(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.26.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18 which represents the daily lag. From the autocorrelation and partial autocorrelation coefficients, Table 4.26.1(b),and the structure of the ACF and PACF, Figure 4.26.1(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model was found to be appropriate, accounted for 68% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.26.1(b) there was no structure to the ACF and PACF of the first differenced data and a model was not determined.

4.26.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.26.2(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.26.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.26.2(b) and the structure of the ACF and PACF, Figure 4.26.2(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model was found to be appropriate and accounted for 74% of the total variance but the lag 1 Autocorrelation coefficient of the residuals had a significant value.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.26.2(b) an ARIMA(1,1,0)(1,0,0)18 model was fitted to the data. This model accounted for 72% of the total variance and the ACF of the residuals showed no structure.

4.26.3. Vertical Solar Irradiance

The time series plot, Figure 4.26.3(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.26.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.26.3(b) and the structure of the ACF and PACF, Figure 4.26.3(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model accounted for 69% of the total variance but the ACF of the residuals had a significant value at lag1. An ARIMA(2,0,0)(1,0,0)18 model accounted for 72% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.26.3(b) an ARIMA(1,1,0)(1,0,0)18 model was fitted to the data. This model was found to be appropriate, accounted for 68% of the total variance and the ACF of the residuals showed no structure.

4.26.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.26.4(a), displays the daily cyclic nature of the data with 18 observations per day. The ACF of the data, Figure 4.26.4(b) also emphasises the periodic nature of the data with damped oscillations repeating at lag 18. From the autocorrelation and partial autocorrelation coefficients, Table 4.26.4(b) and the structure of the ACF and PACF, Figure 4.26.4(b) & (c), an ARIMA(1,0,0)(1,0,0)18 model was fitted to the data. This model accounted for 70% of the total variance and bu the ACF of the residuals had a significant value at lag 1. An ARIMA(2,0,0)(1,0,0)18 model accounted for 71% of the total variance with no structure to the ACF of the residuals.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.26.4(b) an ARIMA(1,1,0)(1,0,0)18 model was fitted to the data. This model was found to be appropriate, accounted for 68% of the total variance but the ACF of the residuals had a significant value at lag 2.

Table 4.26.1 Summary information for Horizontal Solar Irradiance - 20 minute averages (datafile DEC95_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0572	0.0399	0.0057	0.2552

b)

$2/\sqrt{234}=0.131$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.819	0.819	0.116	0.116
2	0.597	-0.222	-0.032	-0.046
3	0.389	-0.084	-0.089	-0.081
4	0.213	-0.055	-0.148	-0.132
18	0.353	0.038	0.097	-0.027

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)	AR1	1.0115	0.0641	15.78	0.11411	0.000494	69
	AR2	-0.2261	0.0642	-3.52			
	CONST	0.0121	0.0014	8.30			
ARIMA(1,0,0)(1,0,0)18	AR1	0.8116	0.0389	20.86	0.11786	0.000510	68
	SAR18	0.1452	0.0666	2.18			
	CONST	0.0089	0.0015	6.03			

Table 4.26.2 Summary information for Log Transformed Horizontal Solar Irradiance - 20 minute averages (datafile DEC95_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0855	0.6838	-5.1664	-1.3659

b)

2/√234=0.131	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.835	0.835	0.193	0.193
2	0.617	-0.265	-0.050	-0.091
3	0.422	-0.027	0.009	0.039
4	0.232	-0.153	-0.146	-0.168
18	0.469	-0.036	0.237	0.128

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)(1,0,0)18	AR1	1.0194	0.0654	15.59	26.5589	0.1155	75
	AR2	-0.2284	0.0650	-3.51			
	SAR18	0.2701	0.0670	4.03			
	CONST	-0.4771	0.0222	-21.44			
ARIMA(1,1,0)(1,0,0)18	AR1	0.1249	0.0661	1.89	30.057	0.1301	72
	SAR18	0.2566	0.0665	3.86			
ARIMA(1,0,0)(1,0,0)18	AR1	0.8268	0.0383	21.57	27.8092	0.1204	74
	SAR18	0.3340	0.0648	5.16			
	CONST	-0.3630	0.0227	-15.97			

Table 4.26.3 Summary information for Vertical Solar Irradiance - 20 minute averages (datafile DEC95_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0975	0.1424	0.0034	0.7638

b)

$2/\sqrt{234}=0.131$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.831	0.831	0.220	0.220
2	0.587	-0.331	-0.117	-0.173
3	0.384	0.033	-0.228	-0.173
4	0.256	0.059	-0.198	-0.138
18	0.178	0.122	-0.005	-0.046

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(2,0,0)(1,0,0)18	AR1	1.1083	0.0622	17.83	1.29144	0.00561	72
	AR2	-0.3333	0.0622	-5.36			
	SAR18	0.0211	0.0662	0.32			
	CONST	0.0211	0.0049	4.30			
ARIMA(1,0,0)(1,0,0)18	AR1	0.8326	0.0366	22.76	1.45204	0.00629	69
	SAR18	0.0132	0.0659	0.20			
	CONST	0.0155	0.0052	2.99			
ARIMA(1,1,0)(1,0,0)18	AR1	0.2205	0.0642	3.44	1.50746	0.00653	68
	SAR18	-0.0107	0.0659	-0.16			

Table 4.26.4 Summary information for Log Transformed Vertical Solar Irradiance - 20 minute averages (datafile DEC95_20) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.1561	1.2578	-5.6767	-0.2695

b)

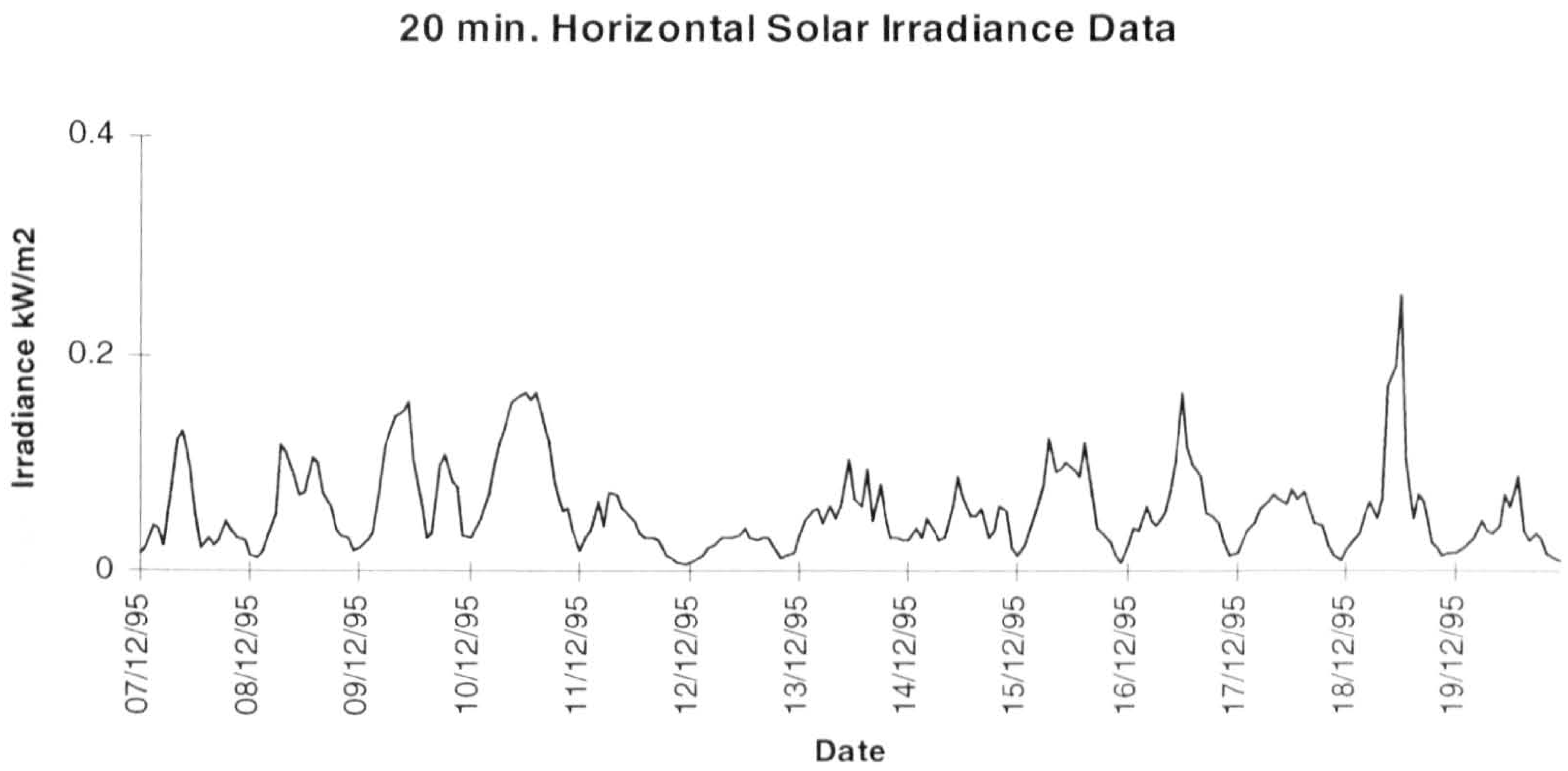
$2/\sqrt{234}=0.131$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.831	0.831	0.149	0.149
2	0.615	-0.241	-0.138	-0.164
3	0.449	0.052	-0.107	-0.062
4	0.319	-0.040	-0.166	-0.169
18	0.281	-0.020	0.016	-0.014

c)

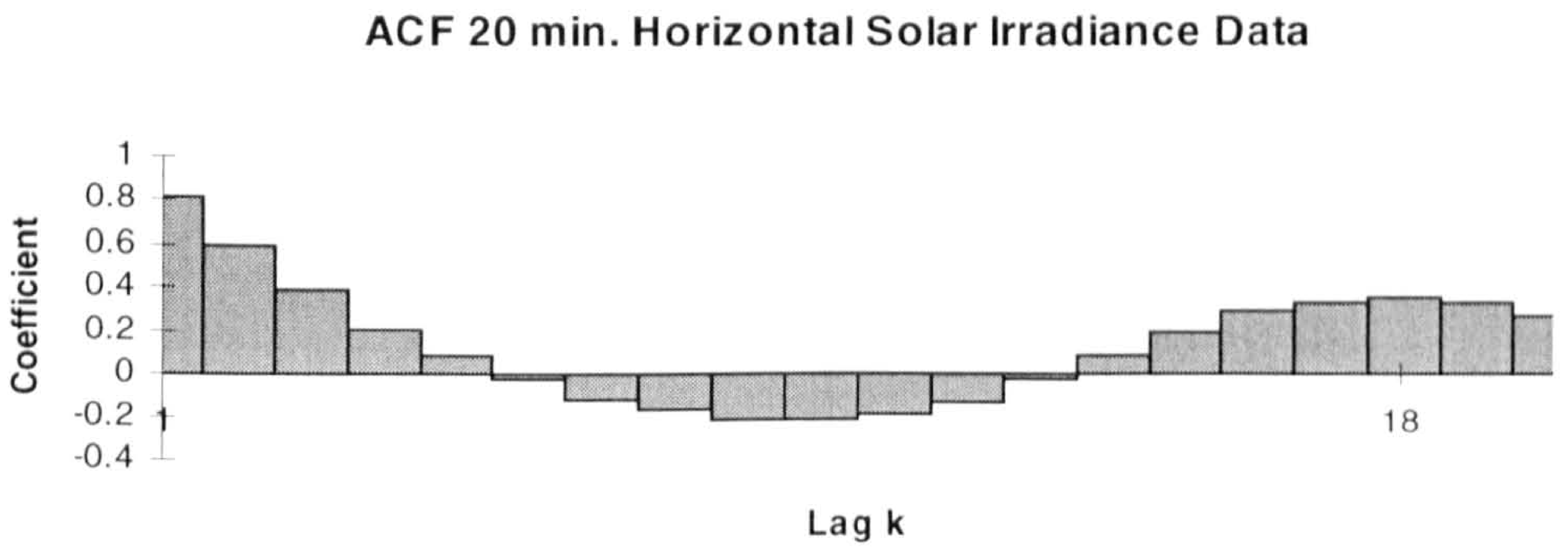
model	parameter	estimate	std. dev.	t-ratio	SS	MS	R^2%
ARIMA(2,0,0)(1,0,0)18	AR1	1.0488	0.0642	16.33	102.905	0.447	71
	AR2	-0.2505	0.0641	-3.91			
	SAR18	0.0264	0.0675	0.39			
	CONST	-0.6283	0.0438	-14.35			
ARIMA(1,1,0)(1,0,0)18	AR1	0.1500	0.0652	2.30	116.406	0.504	68
	SAR18	-0.0050	0.0669	-0.07			
ARIMA(1,0,0)(1,0,0)18	AR1	0.8390	0.0367	22.88	109.623	0.475	70
	SAR18	0.0515	0.0670	0.77			
	CONST	-0.4935	0.0451	-10.94			

Figure 4.26.1 Horizontal Solar Irradiance - 20 minute averages, DEC95_20

a)



b)



c)

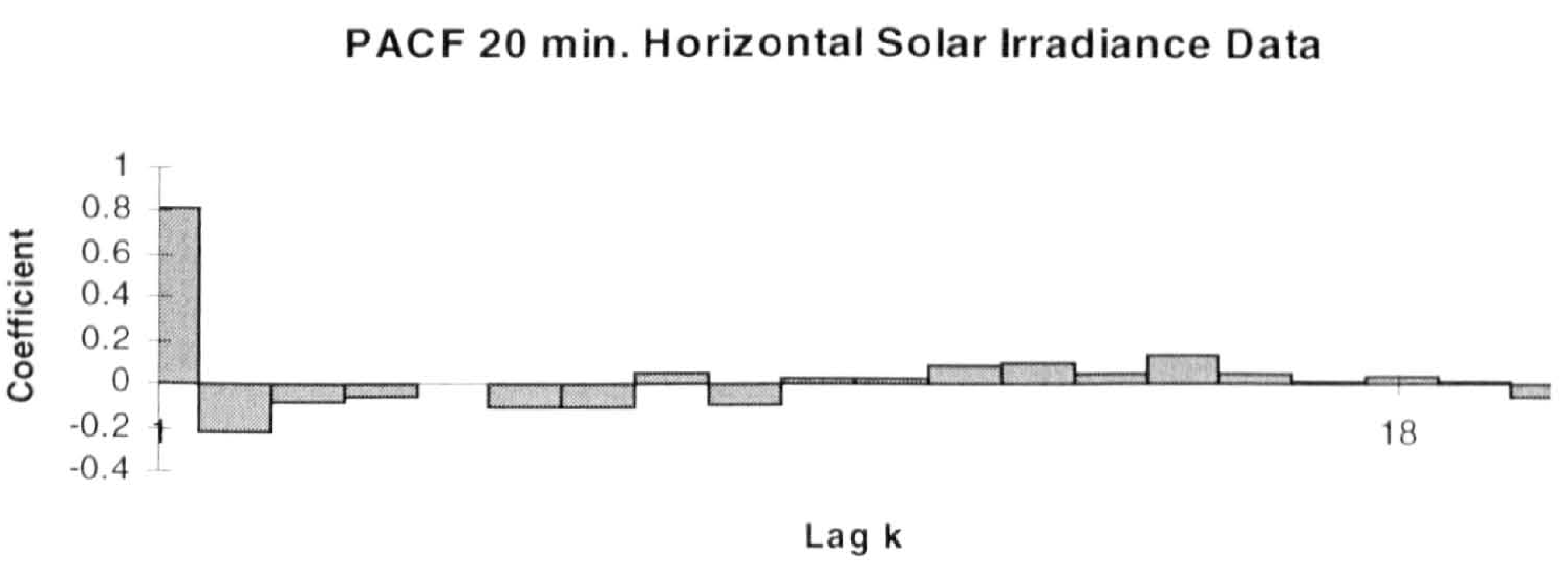
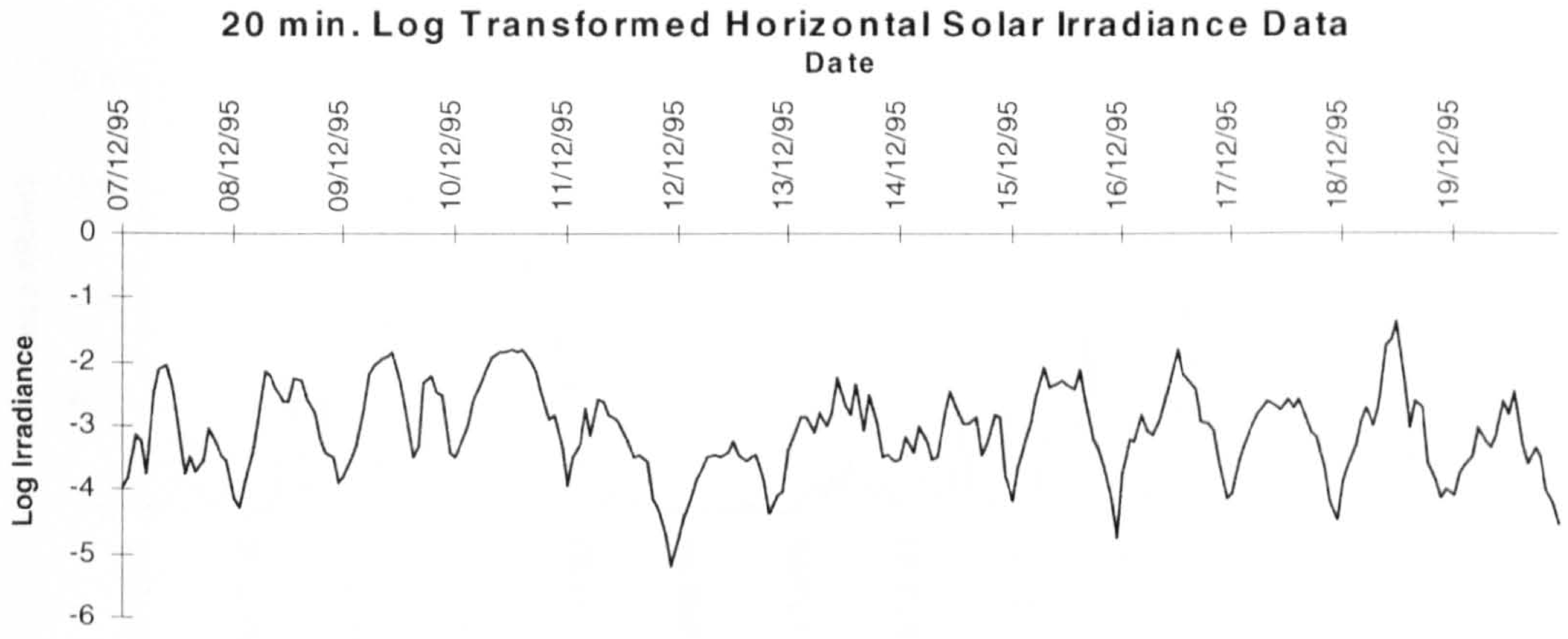
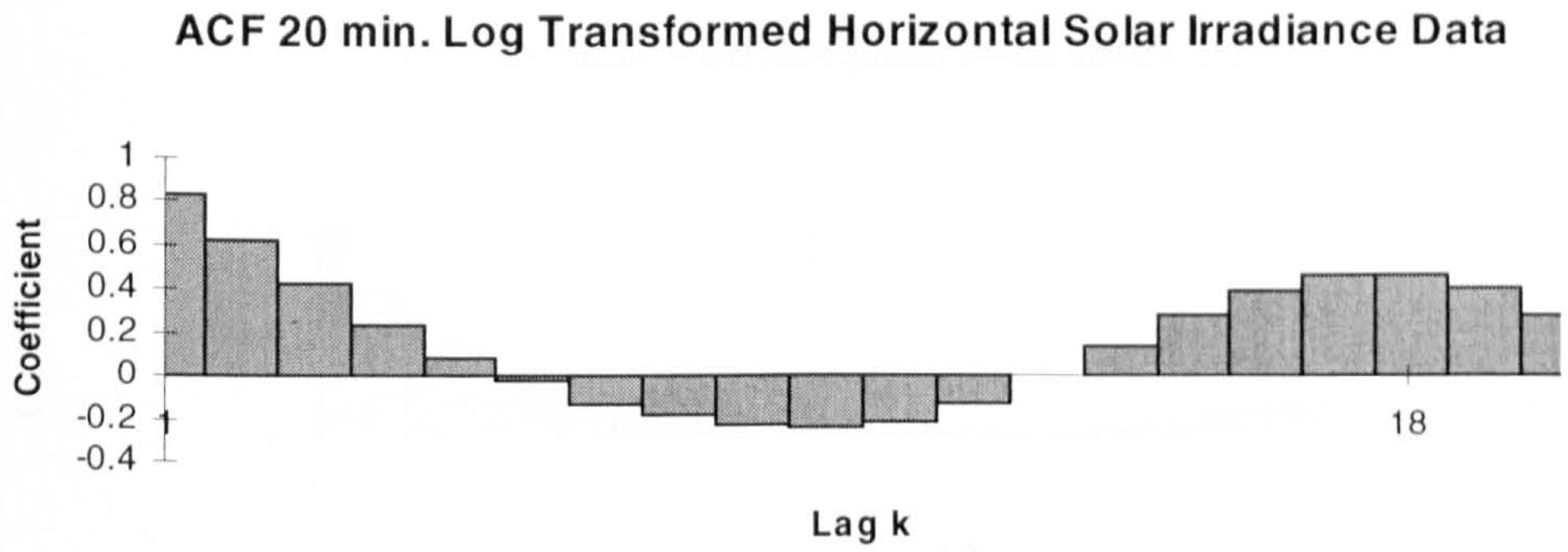


Figure 4.26.2 Log transformed Horizontal Solar Irradiance - 20 minute averages, DEC95_20

a)



b)



c)

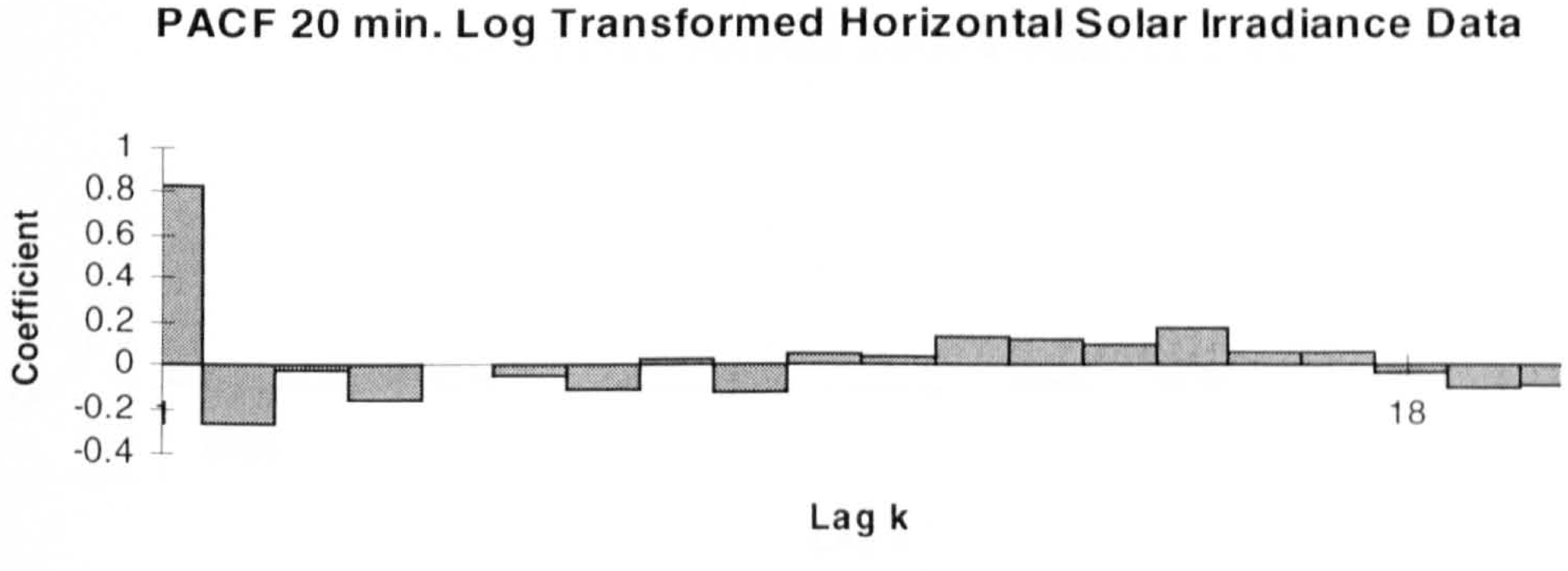
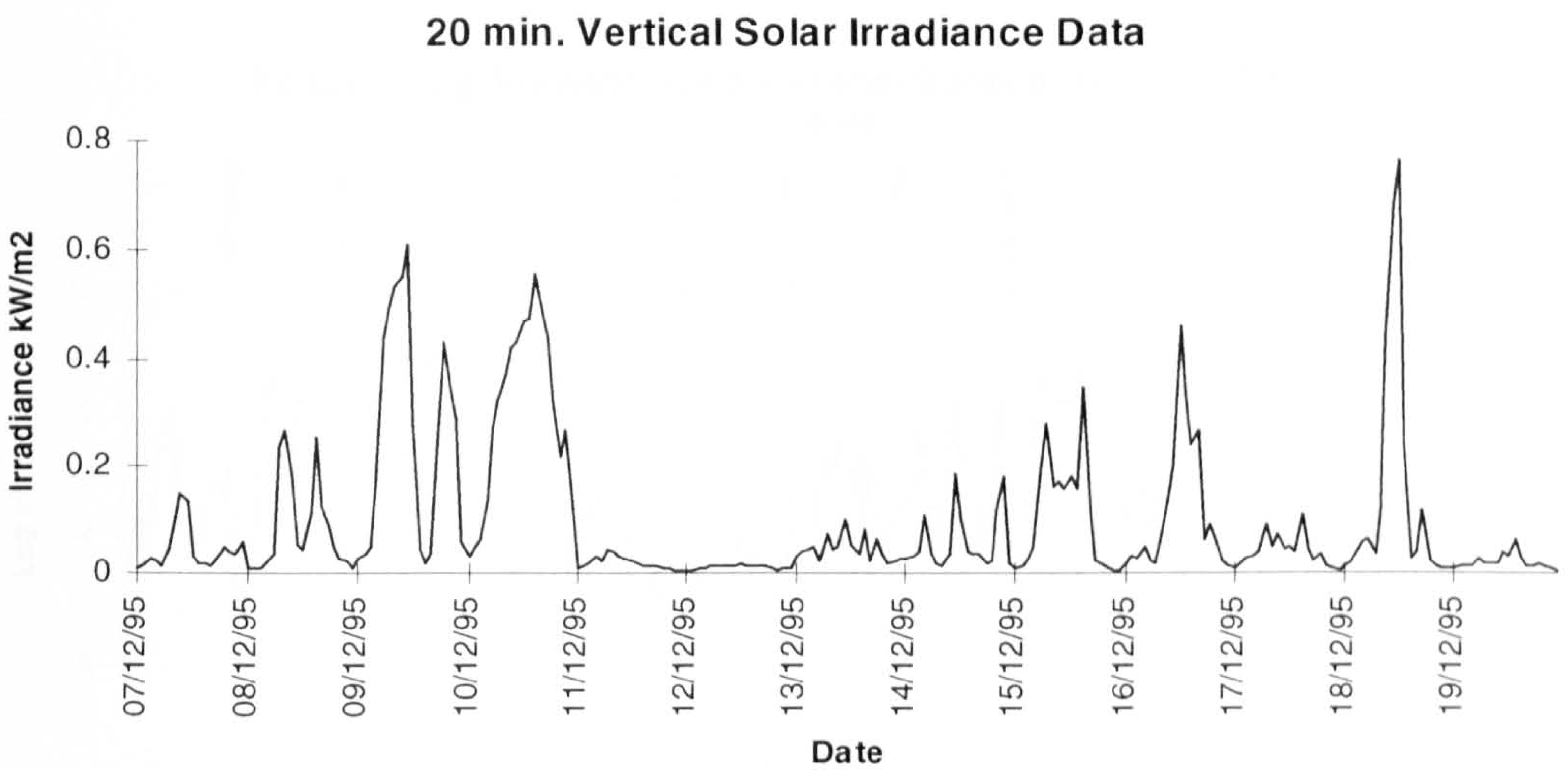
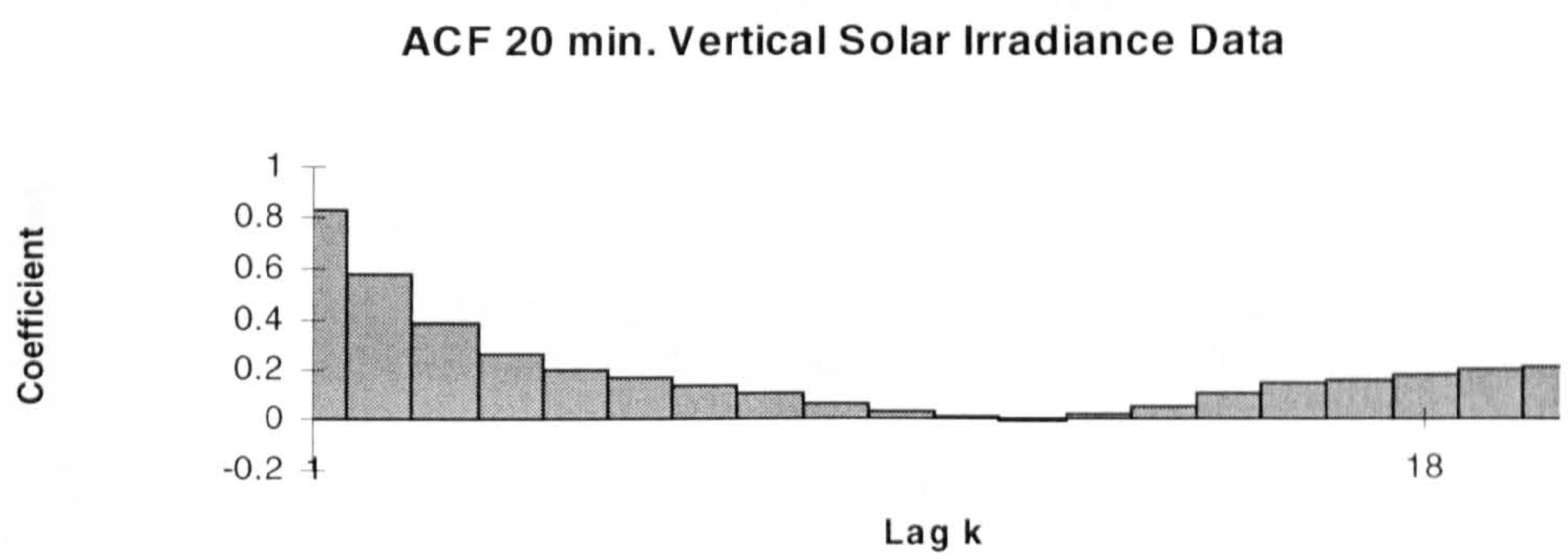


Figure 4.26.3 Vertical Solar Irradiance - 20 minute averages, DEC95_20

a)



b)



c)

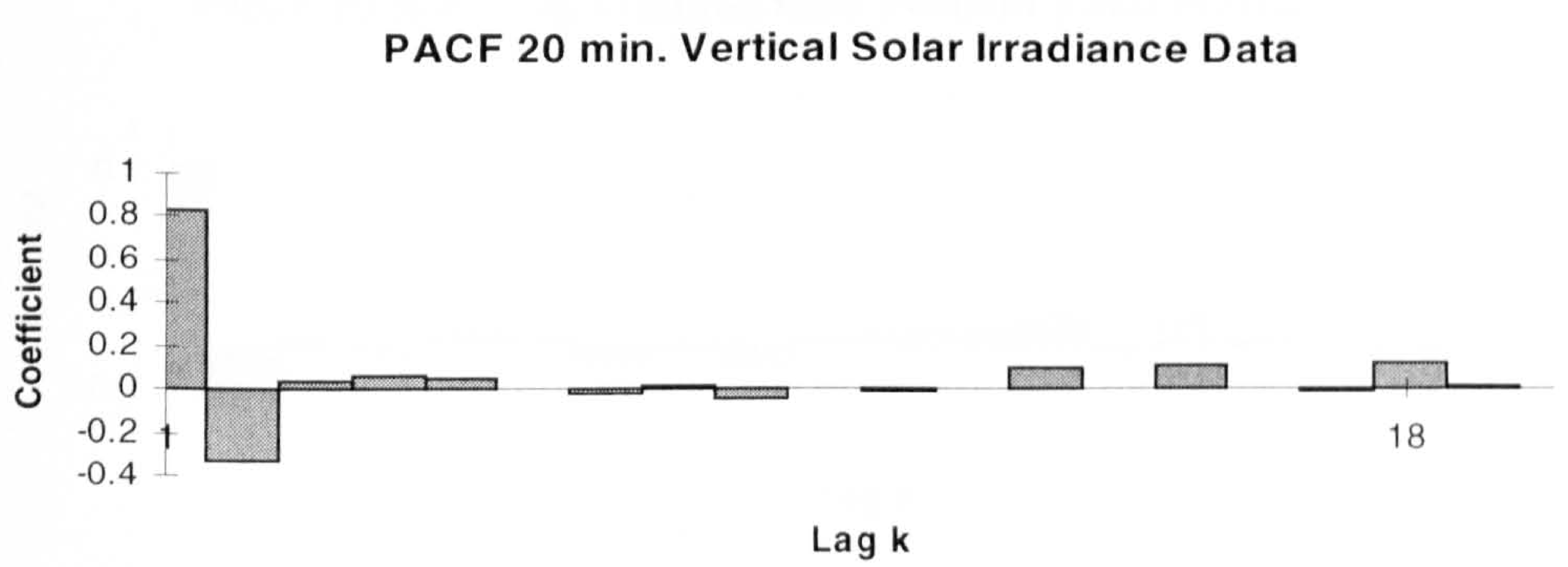
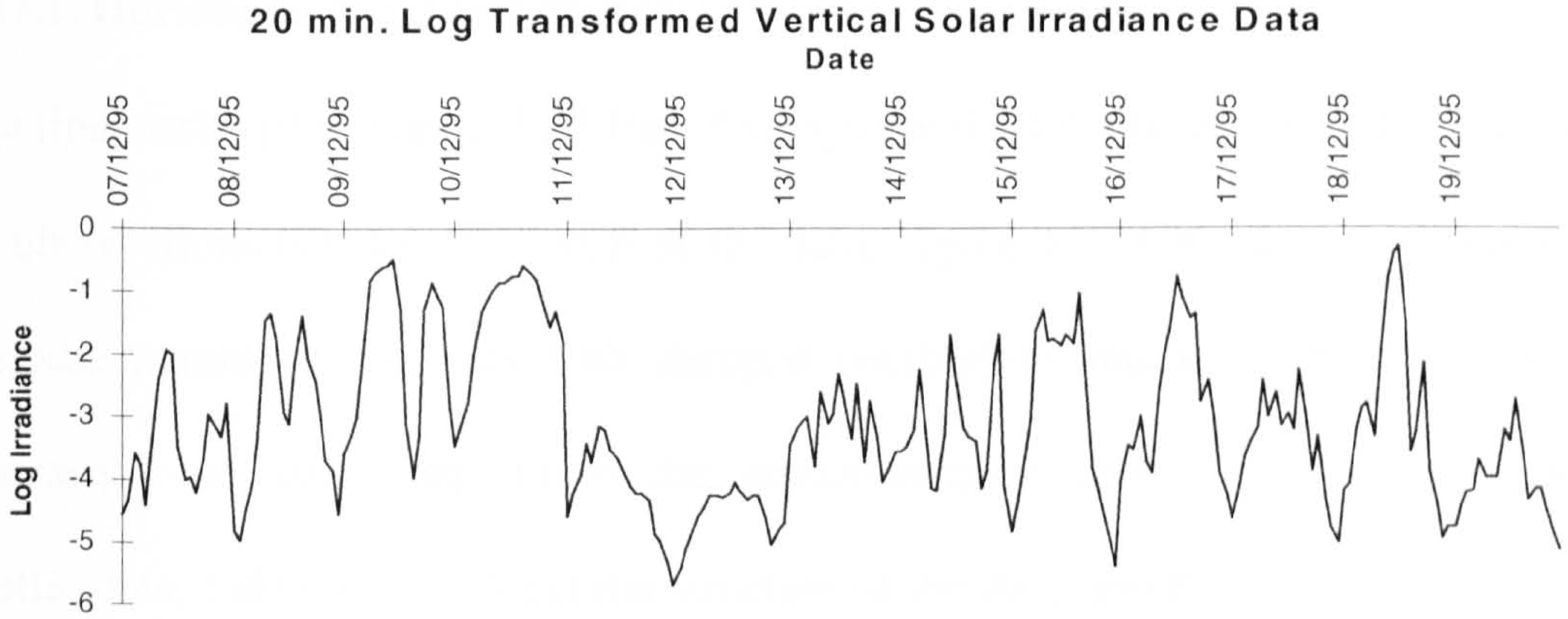
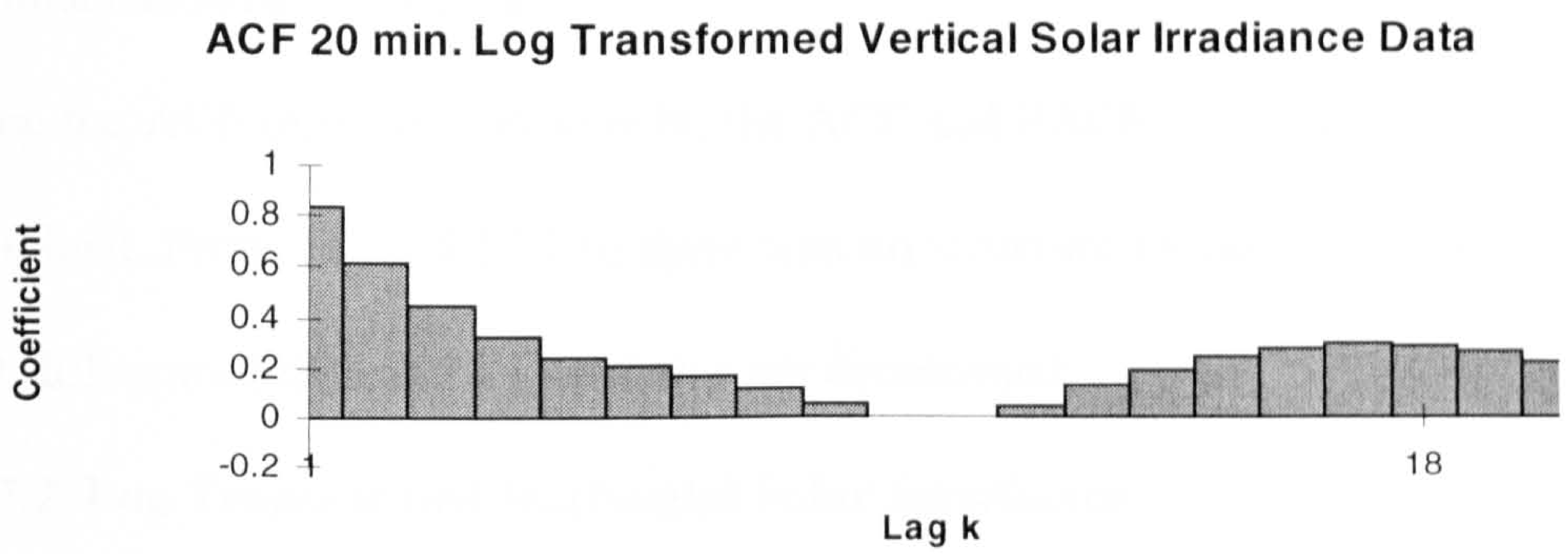


Figure 4.26.4 Log transformed Vertical Solar Irradiance - 20 minute averages, DEC95_20

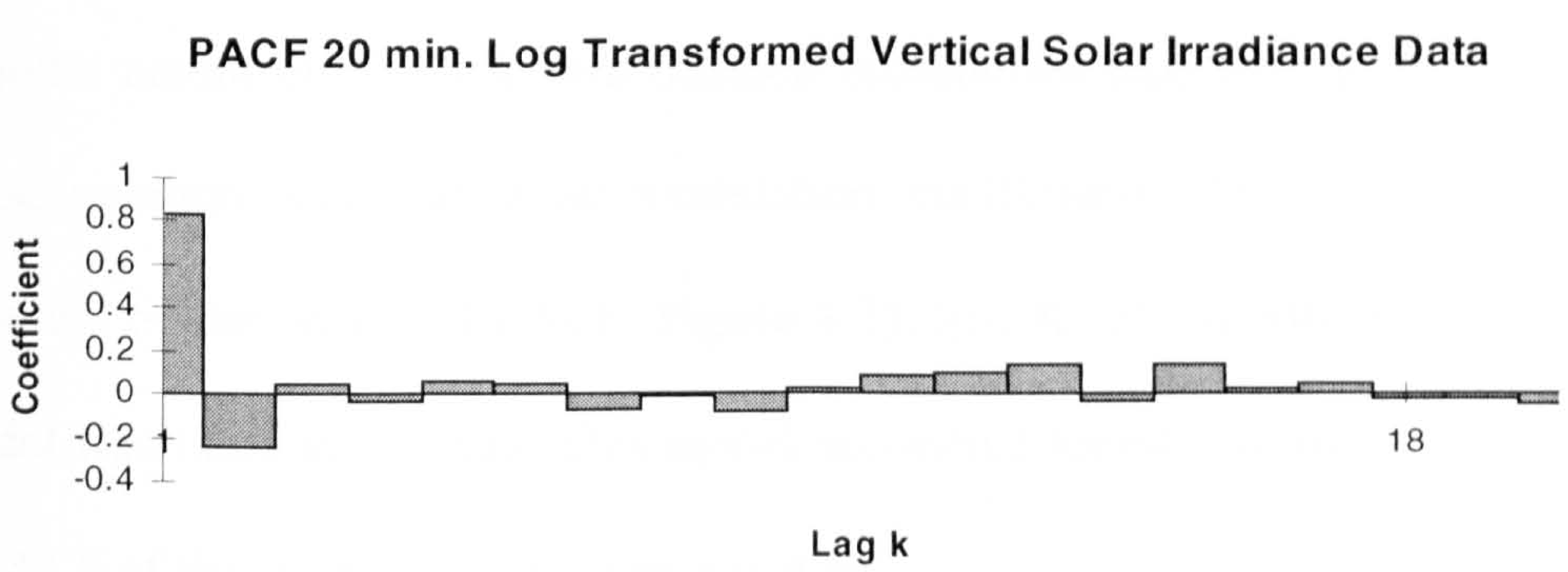
a)



b)



c)



4.27. December 1995 - Thirty minute averages

This data set, known as DEC95_30, contains 30 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 7th and 19th December 1995.

4.27.1. Horizontal Solar Irradiance

The time series plot, Figure 4.27.1(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.27.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12 which represents the daily lag. From the autocorrelation and partial autocorrelation coefficients, Table 4.27.1(b),and the structure of the ACF and PACF, Figure 4.27.1(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model was found to be appropriate, accounted for 56% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.27.1(b) there was no structure to the ACF and PACF of the first differenced data and a model was not determined.

4.27.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.27.2(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.27.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.27.2(b) and the structure of the ACF and PACF, Figure 4.27.2(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model accounted for 64% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.27.2(b) there was no structure to the ACF and PACF of the first differenced data and a model was not determined.

4.27.3. Vertical Solar Irradiance

The time series plot, Figure 4.27.3(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.27.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.27.3(b) and the structure of the ACF and PACF, Figure 4.27.3(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model was found to be appropriate, accounted for 52% of the total variance but the ACF of the residuals had a significant value at lag 3. Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.27.3(b) there was no structure to the ACF and PACF of the first differenced data and a model was not determined.

4.27.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.27.4(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.27.4(b) also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.27.4(b) and the structure of the ACF and PACF, Figure 4.27.4(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model was found to be appropriate, accounted for 56% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.27.2(b) there was no structure to the ACF and PACF of the first differenced data and a model was not determined.

4.27.3. Vertical Solar Irradiance

The time series plot, Figure 4.27.3(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.27.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.27.3(b) and the structure of the ACF and PACF, Figure 4.27.3(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model was found to be appropriate, accounted for 52% of the total variance but the ACF of the residuals had a significant value at lag 3. Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.27.3(b) there was no structure to the ACF and PACF of the first differenced data and a model was not determined.

4.27.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.27.4(a), displays the daily cyclic nature of the data with 12 observations per day. The ACF of the data, Figure 4.27.4(b) also emphasises the periodic nature of the data with damped oscillations repeating at lag 12. From the autocorrelation and partial autocorrelation coefficients, Table 4.27.4(b) and the structure of the ACF and PACF, Figure 4.27.4(b) & (c), an ARIMA(1,0,0)(1,0,0)12 model was fitted to the data. This model was found to be appropriate, accounted for 56% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.27.4(b) there was no structure to the ACF and PACF of the first differenced data and a model was not determined.

Table 4.27.1 Summary information for Horizontal Solar Irradiance - 30 minute averages (datafile DEC95_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0572	0.0389	0.0064	0.2231

b)

$2/\sqrt{156}=0.160$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.730	0.730	0.055	0.055
2	0.435	-0.212	-0.010	-0.013
3	0.147	-0.187	-0.224	-0.223
4	-0.019	0.031	-0.028	-0.004
12	0.365	-0.011	0.138	-0.032

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)12	AR1	0.7037	0.0576	12.22	0.10070	0.000658	56
	SAR12	-0.2945	0.0899	-3.28			
	CONST	0.0219	0.0021	10.66			
ARIMA(3,0,0)	AR1	0.8560	0.0797	10.74	0.09911	0.000652	57
	AR2	-0.0463	0.1057	-0.44			
	AR3	-0.1909	0.0799	-2.39			
	CONST	0.02166	0.0020	10.59			

Table 4.27.2 Summary information for Log Transformed Horizontal Solar Irradiance - 30 minute averages (datafile DEC95_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0753	0.6686	-5.0489	-1.500

b)

$2/\sqrt{156}=0.160$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.757	0.757	0.163	0.163
2	0.451	-0.283	-0.005	-0.032
3	0.160	-0.161	-0.211	-0.211
4	-0.031	0.000	-0.083	-0.015
12	0.477	-0.081	0.284	0.098

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)12	AR1	0.7363	0.0565	13.04	24.4535	0.1598	64
	SAR12	0.3841	0.0782	4.91			
	CONST	-0.5081	0.0321	-15.84			
ARIMA(1,1,0)(1,0,0)12	AR1	-0.0114	0.0849	-0.13	28.0123	0.1831	59
	SAR12	0.3434	0.0819	4.19			

Table 4.27.3 Summary information for Vertical Solar Irradiance - 30 minute averages (datafile DEC95_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0975	0.1395	0.0037	0.6539

b)

$2/\sqrt{156}=0.160$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.725	0.725	0.052	0.052
2	0.433	-0.219	-0.192	-0.195
3	0.224	0.020	-0.276	-0.264
4	0.176	0.138	0.008	-0.011
12	0.179	0.020	-0.036	-0.160

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)12	AR1	0.7291	0.0556	13.12	1.41945	0.00928	52
	SAR12	-0.0030	0.0811	-0.00			
	CONST	0.0256	0.0077	3.32			
ARIMA(1,0,0)	AR1	0.7290	0.0553	13.18	1.41945	0.00922	52
	CONST	0.0256	0.0077	3.33			

Table 4.27.4 Summary information for Log Transformed Vertical Solar Irradiance - 30 minute averages (datafile DEC95_30) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.1289	1.2421	-5.6021	-0.4248

b)

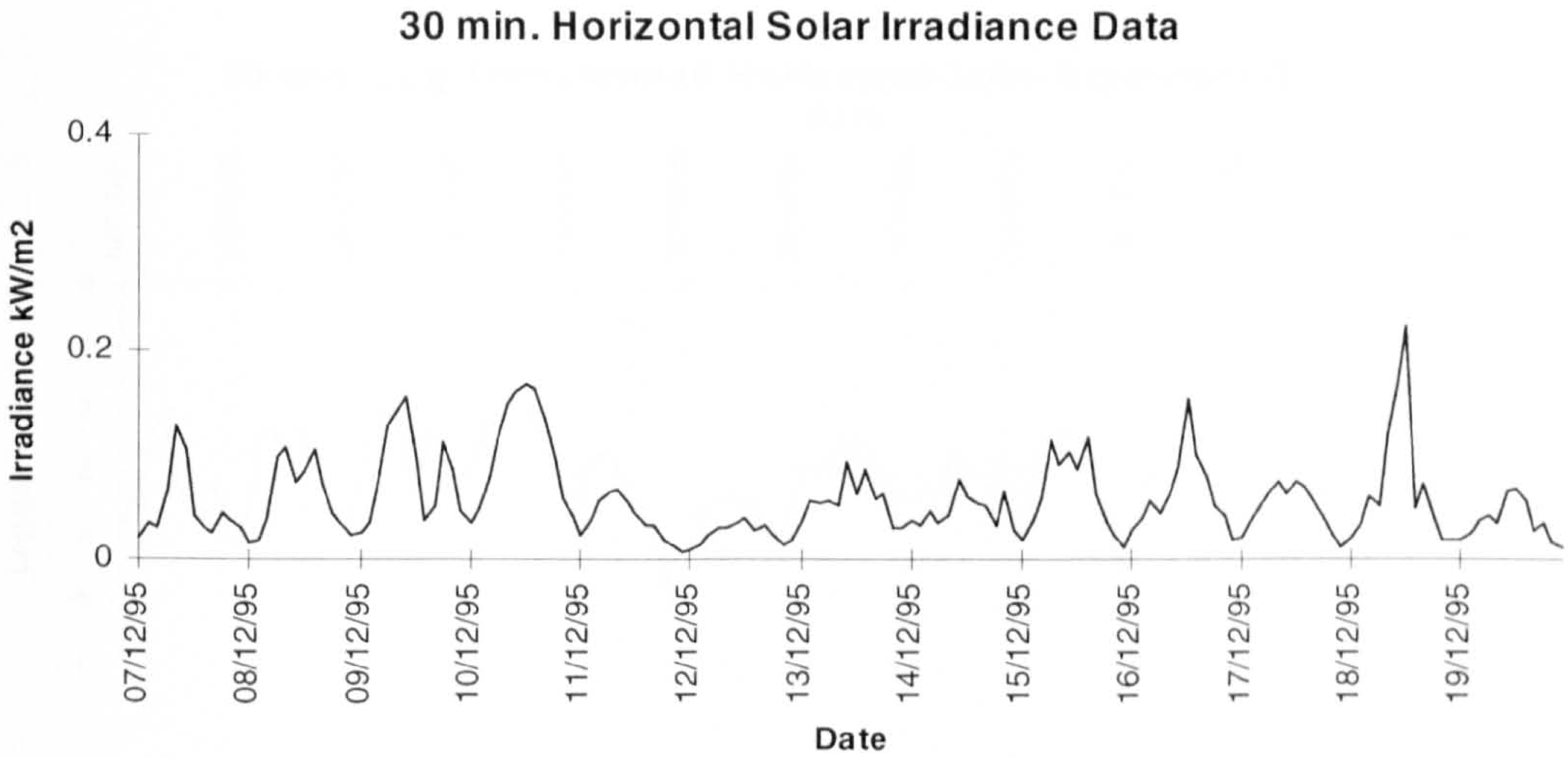
$2/\sqrt{156}=0.160$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.740	0.740	0.031	0.031
2	0.471	-0.170	-0.160	-0.161
3	0.285	0.006	-0.228	-0.223
4	0.213	0.101	0.022	0.004
12	0.288	-0.049	0.022	-0.030

c)

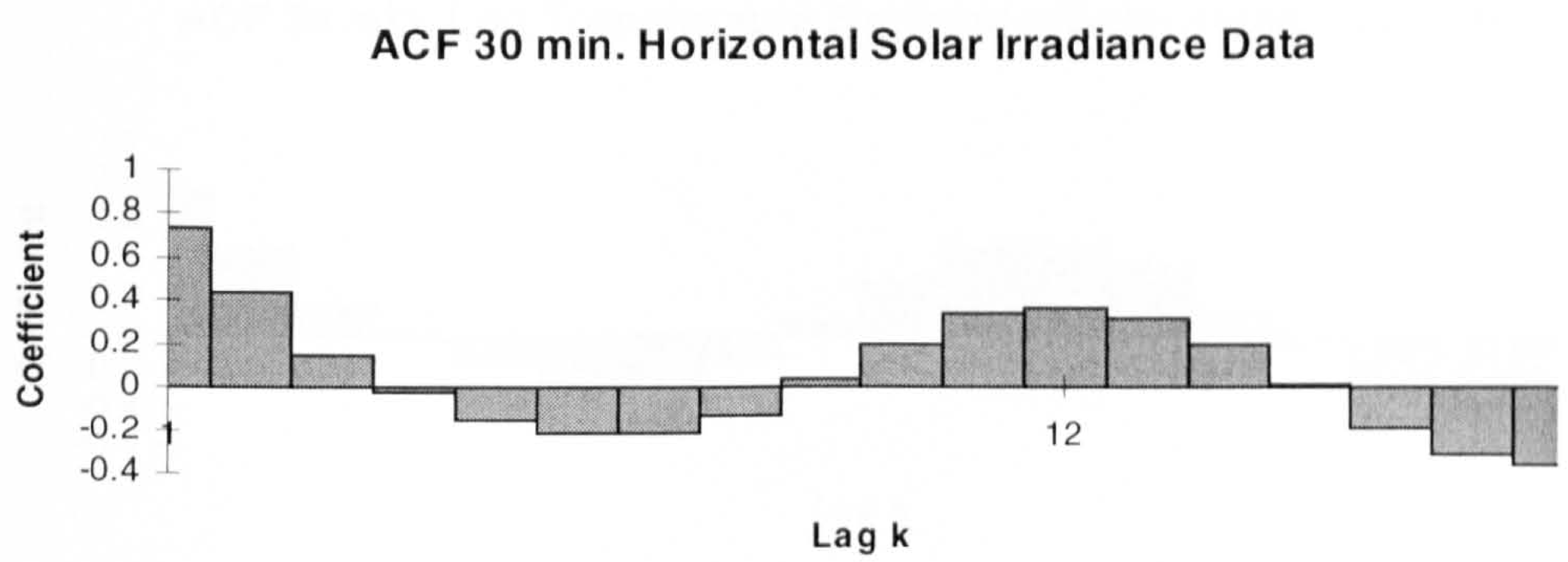
model	parameter	estimate	std. dev.	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)12	AR1	0.7448	0.0553	13.47	104.315	0.682	56
	SAR12	0.0791	0.0825	0.96			
	CONST	-0.7500	0.0662	-11.33			
ARIMA(1,0,0)	AR1	0.7566	0.0536	14.10	104.816	0.681	56
	CONST	-0.7761	0.0662	-11.73			

Figure 4.27.1 Horizontal Solar Irradiance - 30 minute averages, DEC95_30

a)



b)



c)

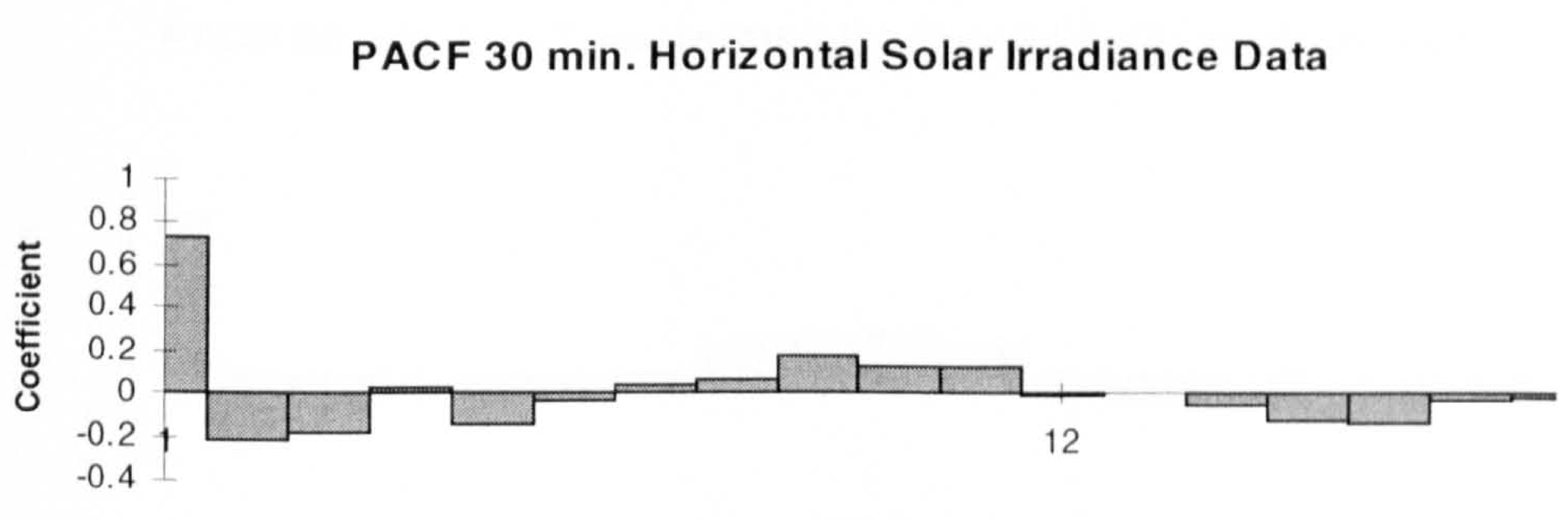
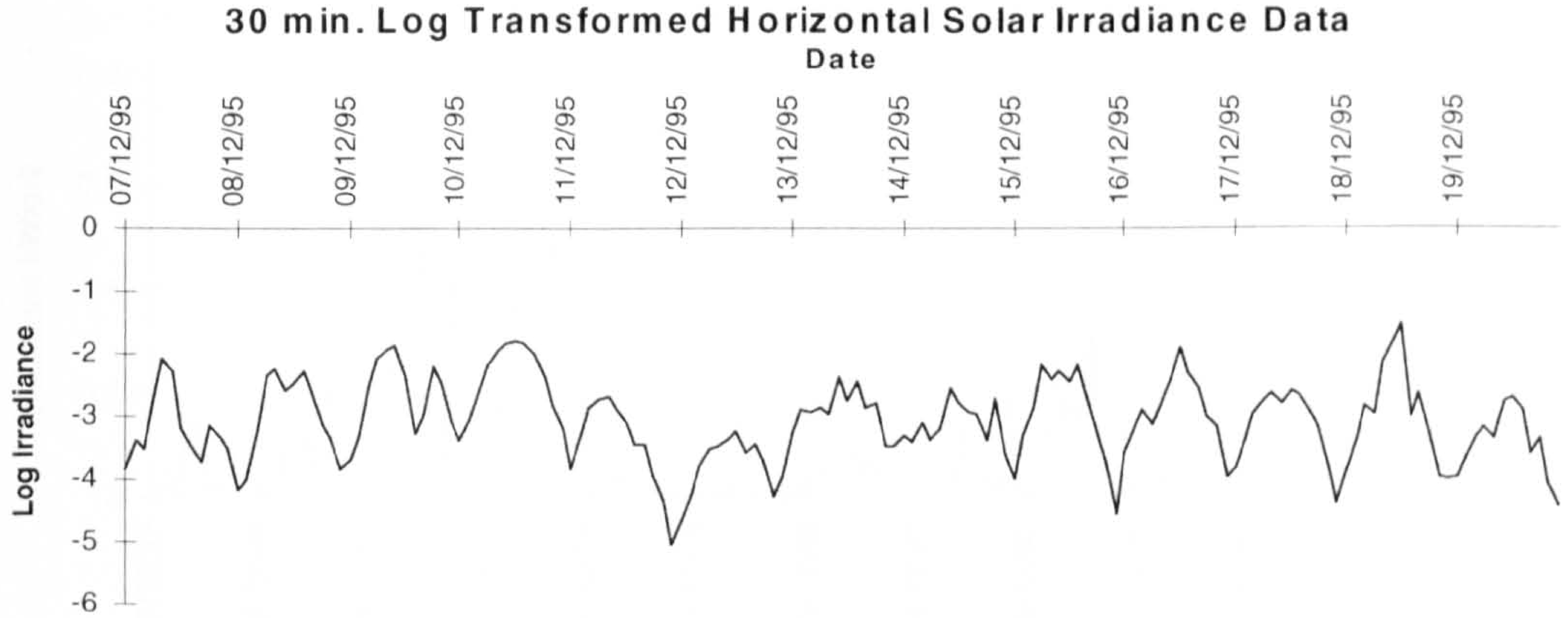
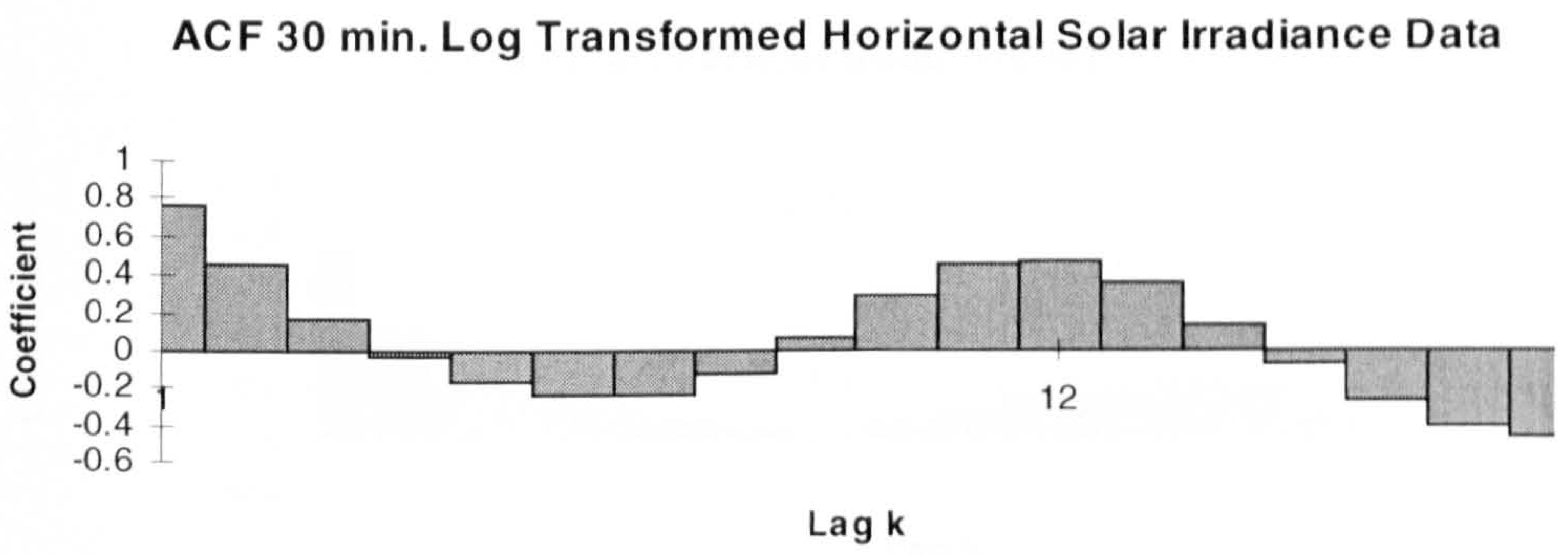


Figure 4.27.2 Log transformed Horizontal Solar Irradiance - 30 minute averages, DEC95_30

a)



b)



c)

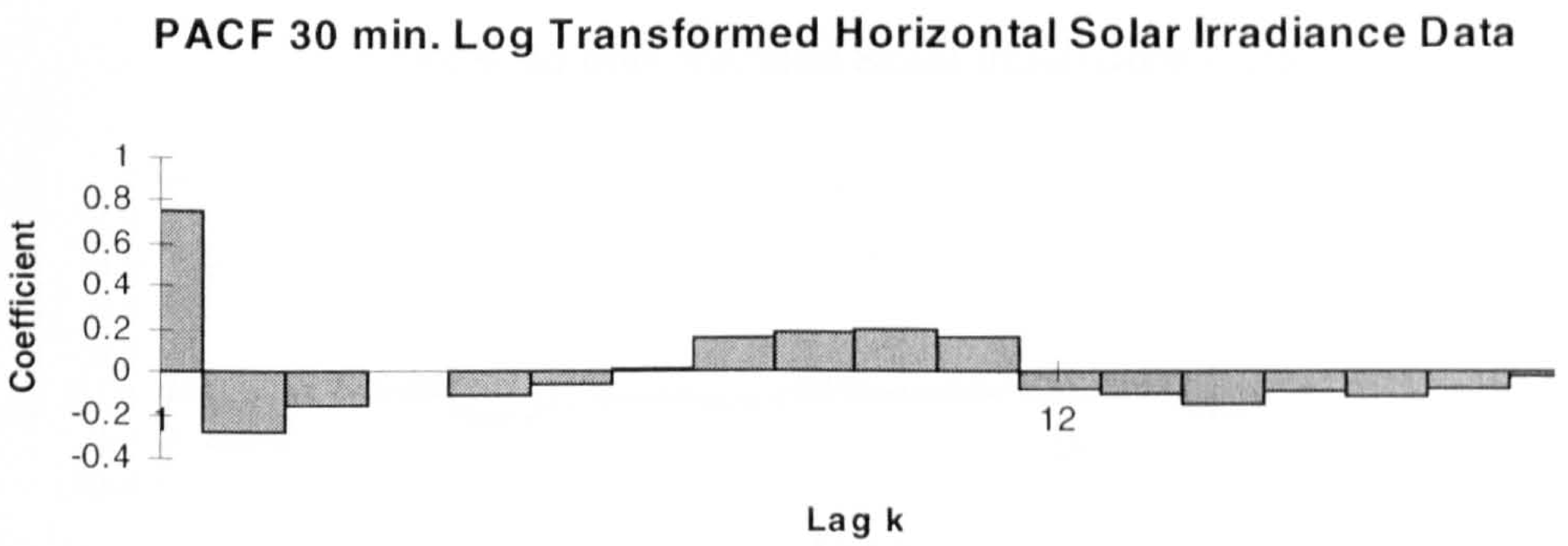
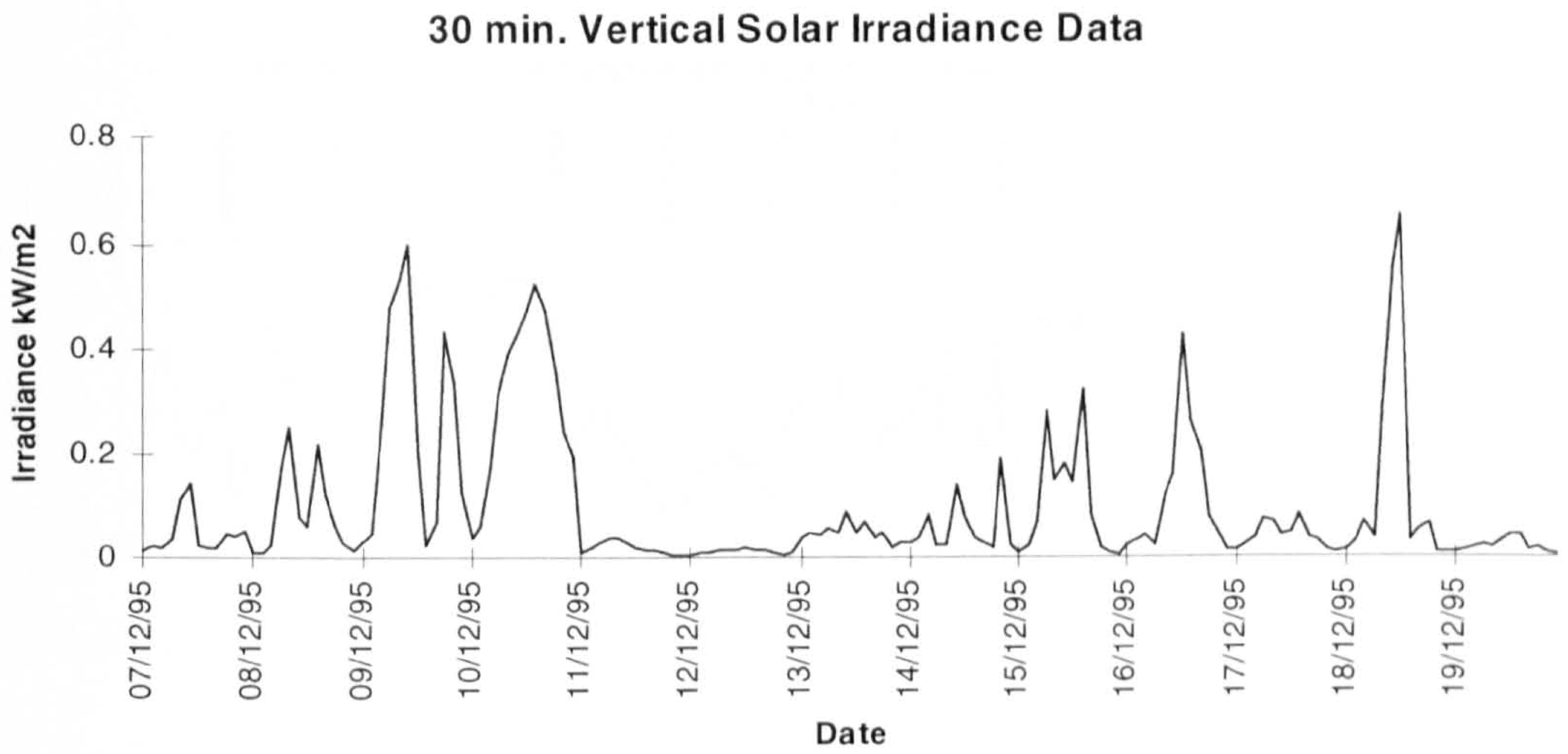
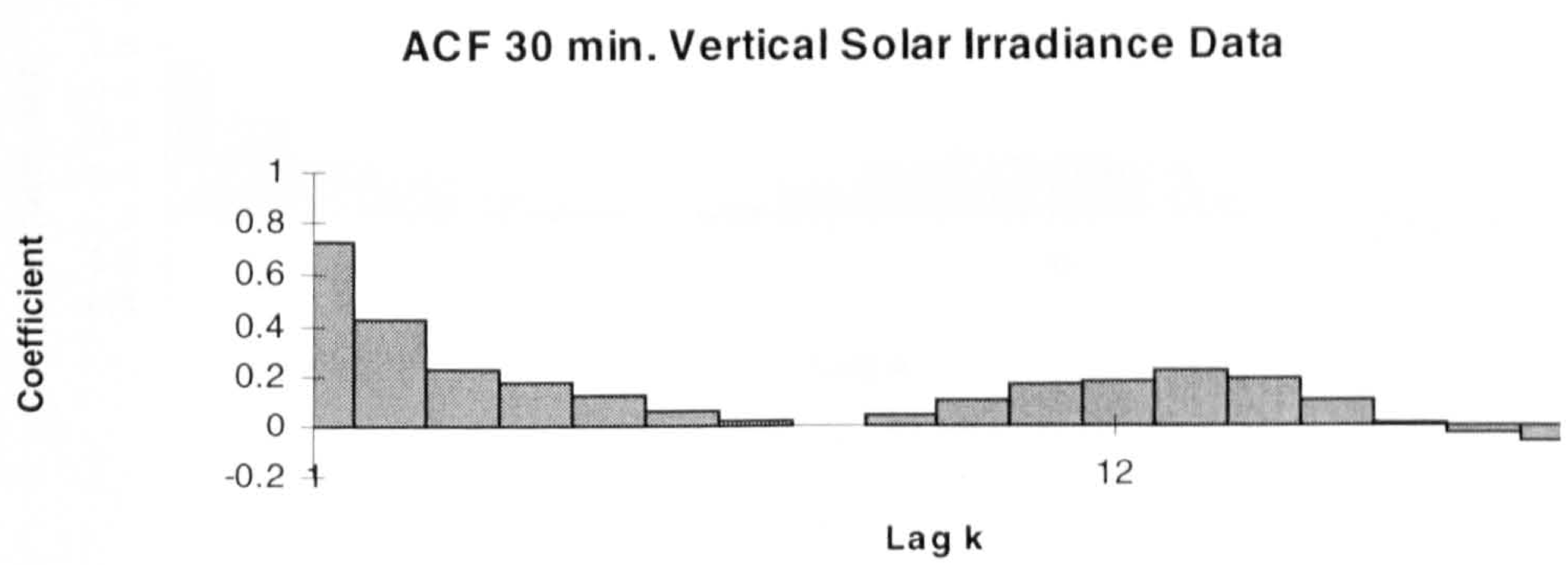


Figure 4.27.3 Vertical Solar Irradiance - 30 minute averages, DEC95_30

a)



b)



c)

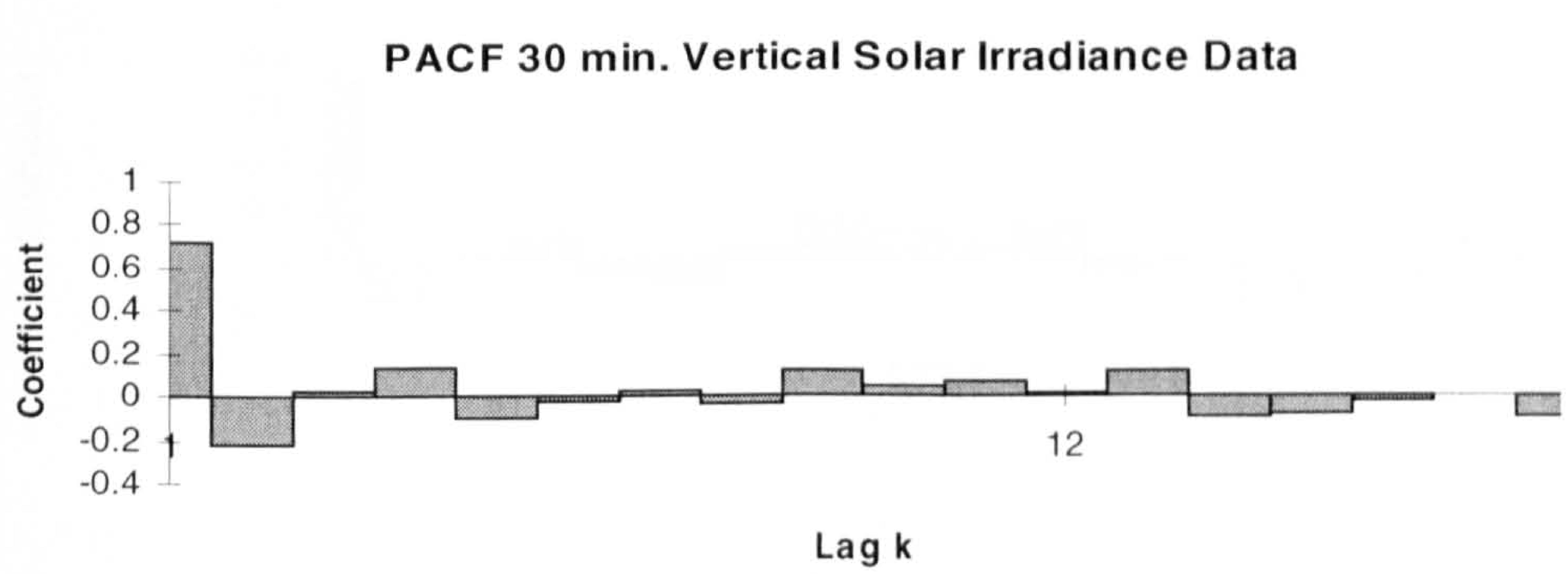
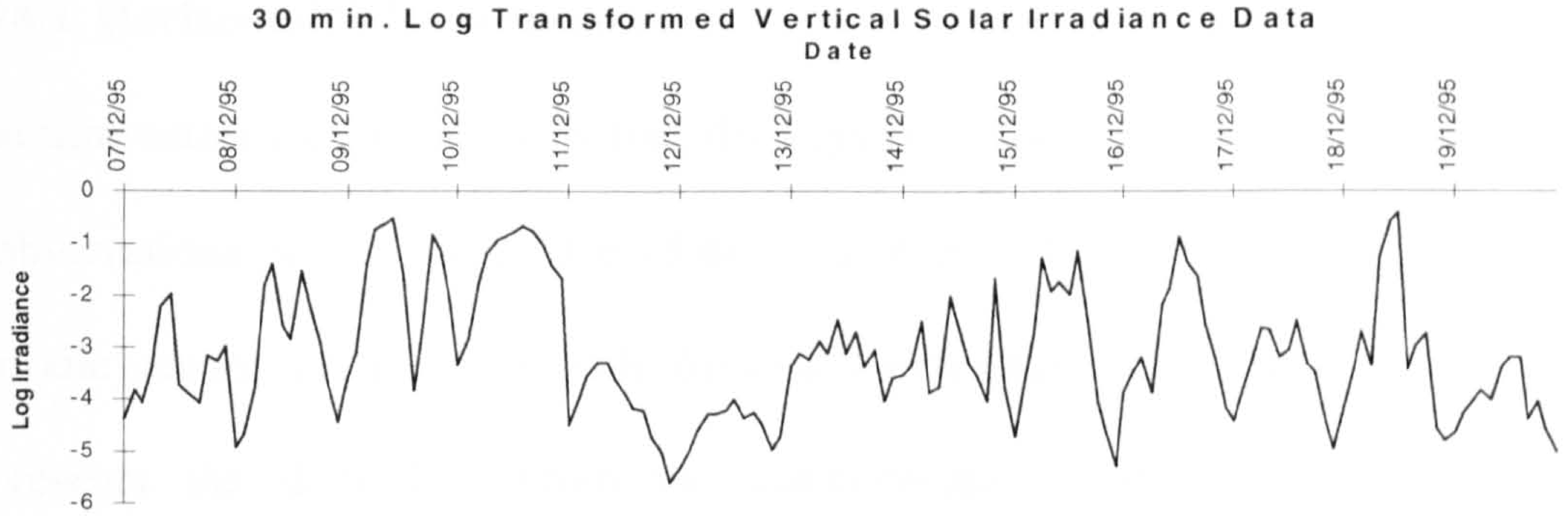
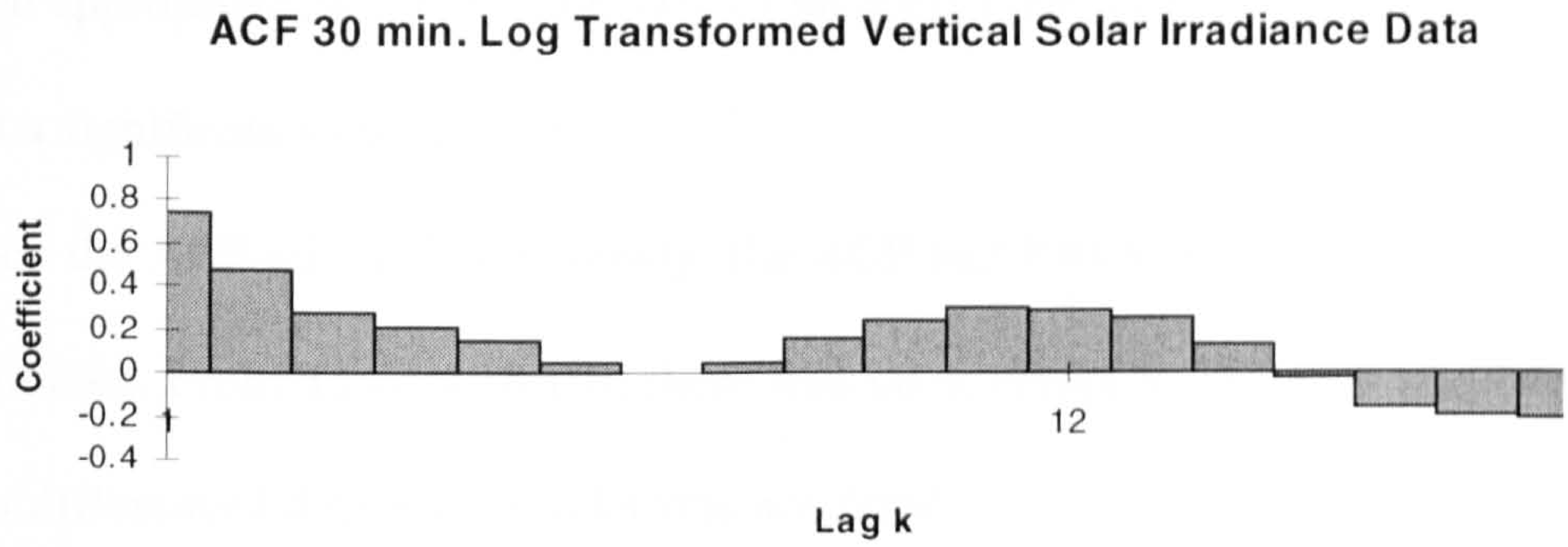


Figure 4.27.4 Log transformed Vertical Solar Irradiance - 30 minute averages, DEC95_30

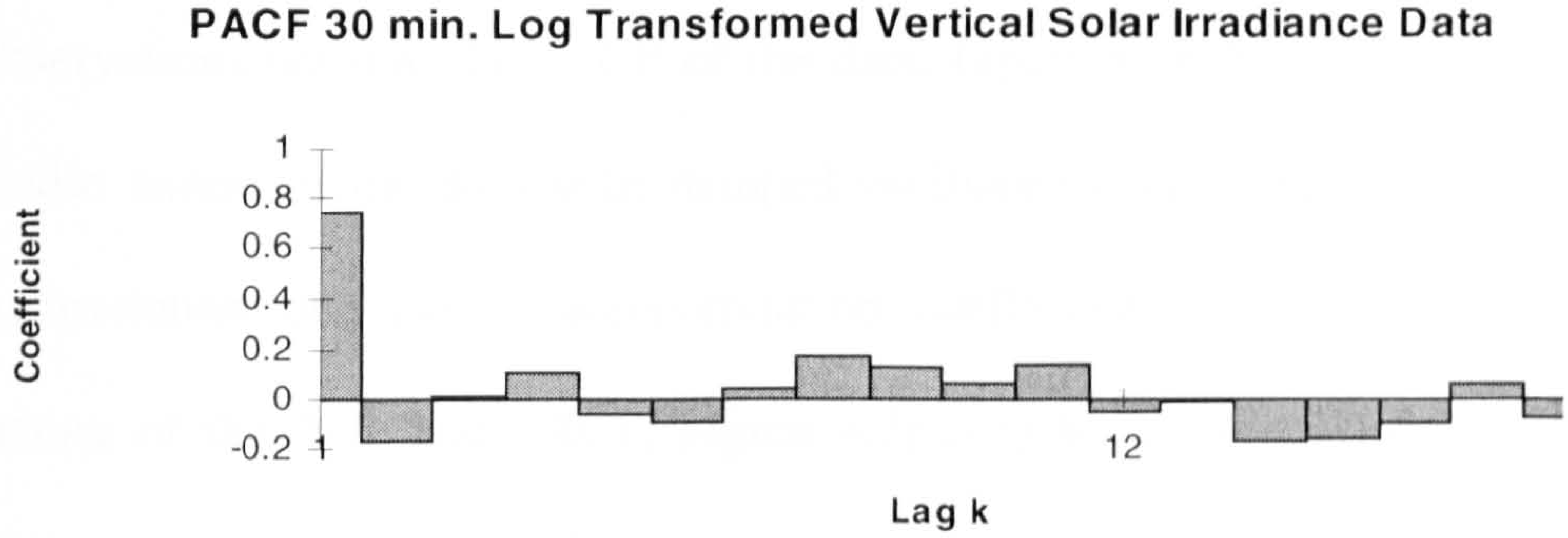
a)



b)



c)



4.28. December 1995 - Sixty minute averages

This data set, known as DEC95_60, contains 60 minute averaged Horizontal and Vertical Global Solar Irradiance data recorded between 7th and 19th December 1995.

4.28.1. Horizontal Solar Irradiance

The time series plot, Figure 4.28.1(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.28.1(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6 which represents the daily lag. From the autocorrelation and partial autocorrelation coefficients, Table 4.28.1(b),and the structure of the ACF and PACF, Figure 4.28.1(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model was found to be appropriate, accounted for 44% of the total variance but the ACF of the residuals had a significant value at lag 6.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.28.1(b) there was no structure to the ACF and PACF of the first differenced data and a model was not fitted.

4.28.2. Log Transformed Horizontal Solar Irradiance

The time series plot, Figure 4.28.2(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.28.2(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.28.2(b) and the structure of the ACF and PACF, Figure 4.28.2(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model accounted for 55% of the total variance but the ACF of the residuals had a significant value at lag 6.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.28.2(b) there was no structure to the ACF and PACF of the first differenced data and a model was not determined.

4.28.3. Vertical Solar Irradiance

The time series plot, Figure 4.28.3(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.28.3(b), also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.28.3(b) and the structure of the ACF and PACF, Figure 4.28.3(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model was found to be appropriate, accounted for 36% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.28.3(b) there was no structure to the ACF and PACF of the first differenced data and a model was not fitted.

4.28.4. Log Transformed Vertical Solar Irradiance

The time series plot, Figure 4.28.4(a), displays the daily cyclic nature of the data with 6 observations per day. The ACF of the data, Figure 4.28.4(b) also emphasises the periodic nature of the data with damped oscillations repeating at lag 6. From the autocorrelation and partial autocorrelation coefficients, Table 4.28.4(b) and the structure of the ACF and PACF, Figure 4.28.4(b) & (c), an ARIMA(1,0,0)(1,0,0)6 model was fitted to the data. This model was found to be appropriate, accounted for 41% of the total variance and the ACF of the residuals showed no structure.

Since the ACF tails-off very slowly, the ACF and PACF of the first differences were examined. From Table 4.28.4(b) there was no structure to the ACF and PACF of the first differenced data and a model was not fitted.

Table 4.28.1 Summary information for Horizontal Solar Irradiance - 60 minute averages (datafile DEC95_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0572	0.0358	0.0096	0.1637

b)

$2/\sqrt{78}=0.226$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.540	0.540	0.14	0.124
2	-0.018	-0.437	-0.341	-0.361
3	-0.239	0.019	-0.395	-0.342
4	-0.136	0.058	-0.292	-0.444
6	0.411	0.046	0.428	0.049

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.5686	0.0948	6.00	0.05304	0.000707	44
	SAR6	0.4917	0.1011	4.86			
	CONST	0.0119	0.0030	3.95			

Table 4.28.2 Summary information for Log Transformed Horizontal Solar Irradiance - 60 minute averages (datafile DEC95_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0488	0.6296	-4.6450	-1.8099

b)

$2/\sqrt{78}=0.226$	Original		First Differenced	
Lag	ACF	PACF	ACF	PACF
1	0.525	0.525	0.114	0.114
2	-0.012	-0.398	-0.309	-0.326
3	-0.232	-0.023	-0.387	-0.344
4	-0.134	0.069	-0.400	-0.554
6	0.497	0.013	0.563	0.254

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	R^2%
ARIMA(1,0,0)(1,0,0)6	AR1	0.6170	0.0912	6.76	13.4119	0.1788	55
	SAR6	0.6511	0.0922	7.07			
	CONST	-0.4165	0.0479	-8.68			
ARIMA(1,1,0)(1,0,0)6	AR1	-0.2653	0.1136	-2.33	15.3621	0.2048	46
	SAR6	0.7485	0.0841	8.90			
ARIMA(0,1,0)(1,0,0)6	SAR6	0.6721	0.0890	7.55	16.3224	0.2148	46

Table 4.28.3 Summary information for Vertical Solar Irradiance - 60 minute averages (datafile DEC95_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
0.0975	0.1275	0.0051	0.5646

b)

$2/\sqrt{78}=0.226$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.583	0.583	-0.036	-0.036
2	0.198	-0.216	-0.311	-0.313
3	0.076	0.098	-0.079	-0.117
4	0.011	-0.072	-0.190	-0.337
6	0.238	0.119	0.222	-0.019

c)

model	parameter	estimate	std. dev	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)6	AR1	0.5857	0.0940	6.23	0.77338	0.010312	36
	SAR6	0.2368	0.1127	2.10			
	CONST	0.0290	0.0115	2.52			

Table 4.28.4 Summary information for Log Transformed Vertical Solar Irradiance - 60 minute averages (datafile DEC95_60) : a) Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients; c) Summary information on fitted ARIMA models

a)

mean	std. dev.	minimum	maximum
-3.0480	1.2080	-5.2850	-0.5720

b)

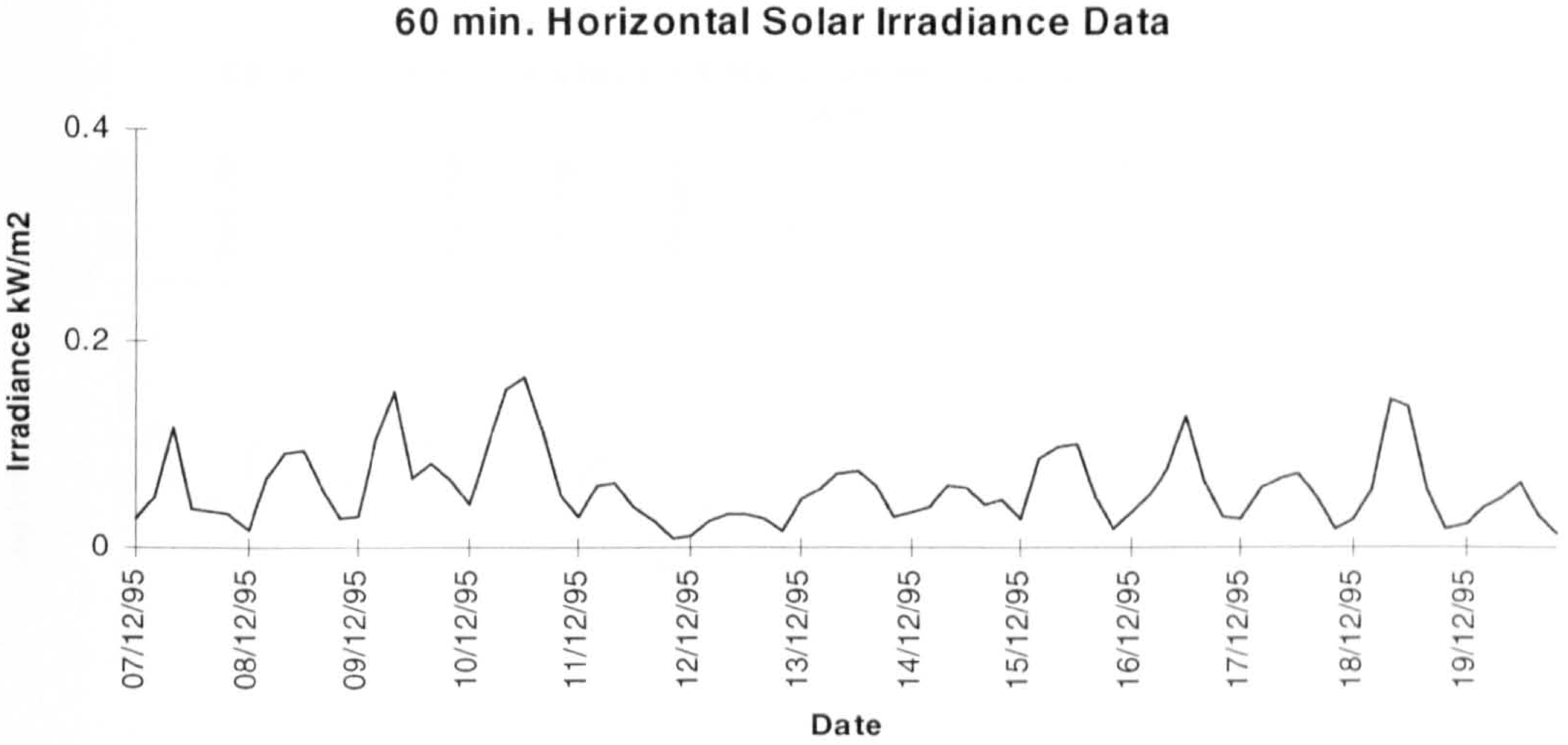
$2/\sqrt{78}=0.226$	Original		First Differenced	
lag	ACF	PACF	ACF	PACF
1	0.580	0.580	-0.089	-0.089
2	0.243	-0.139	-0.171	-0.181
3	0.075	-0.007	-0.212	-0.256
4	0.055	0.064	-0.292	-0.426
6	0.340	0.037	0.305	0.141

c)

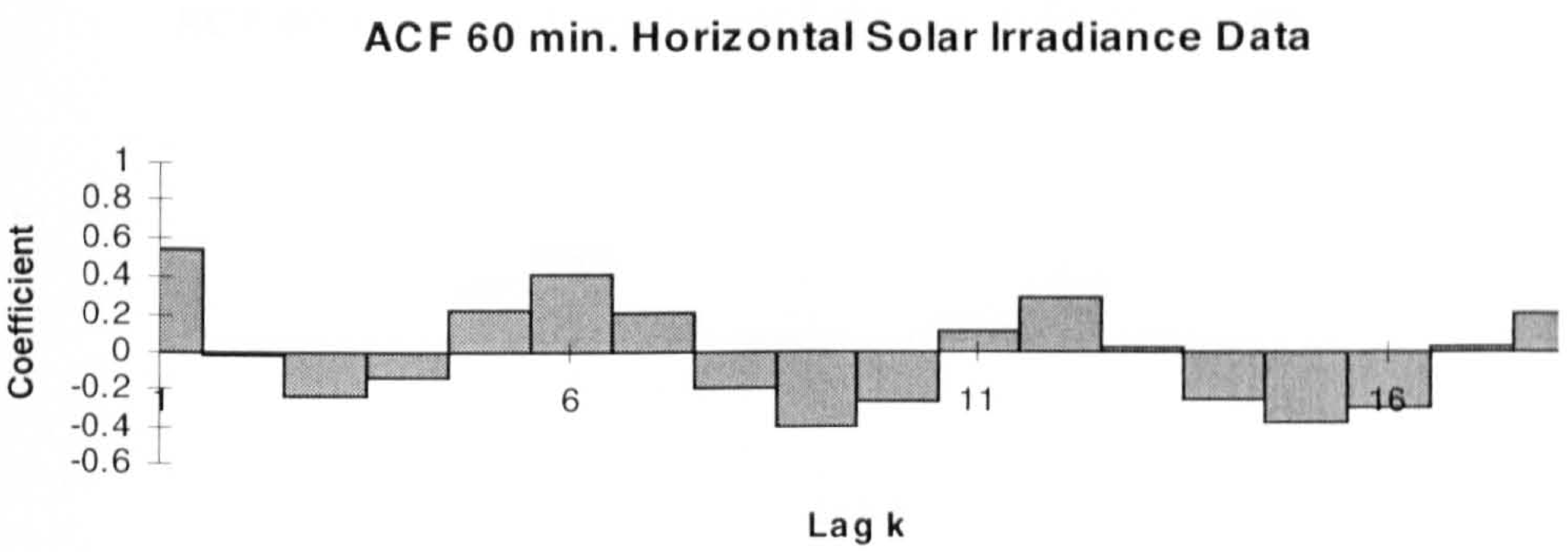
model	parameter	estimate	std. dev.	t-ratio	SS	MS	$R^2\%$
ARIMA(1,0,0)(1,0,0)6	AR1	0.5885	0.0944	6.23	64.0791	0.8544	41
	SAR6	0.3631	0.1098	3.31			
	CONST	-0.8224	0.1049	-7.84			

Figure 4.28.1 Horizontal Solar Irradiance - 60 minute averages, DEC95_60

a)



b)



c)

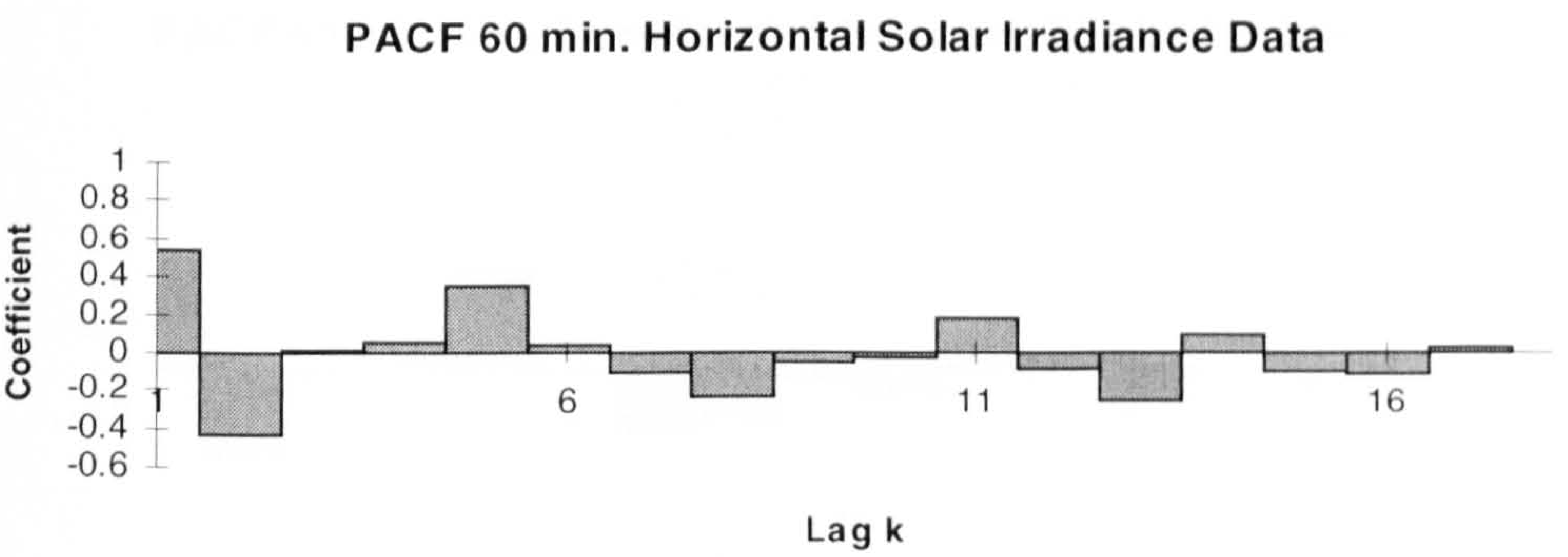
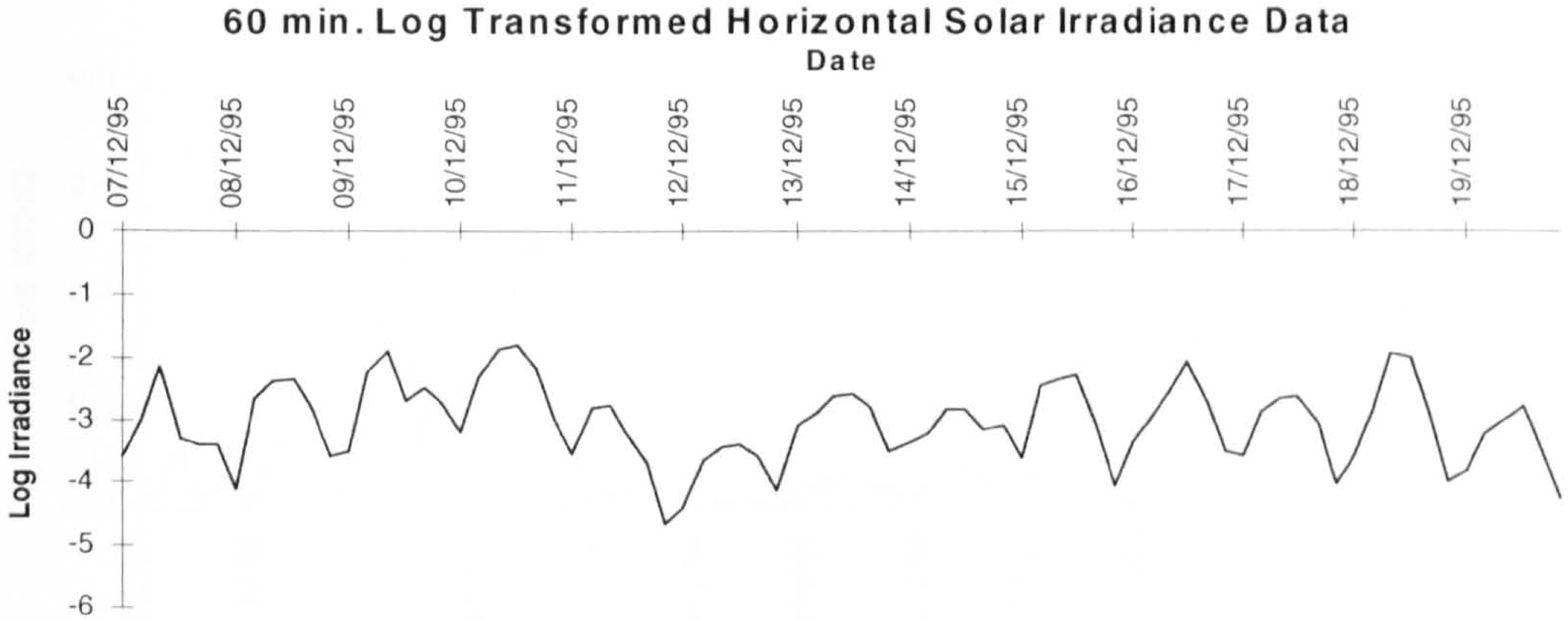
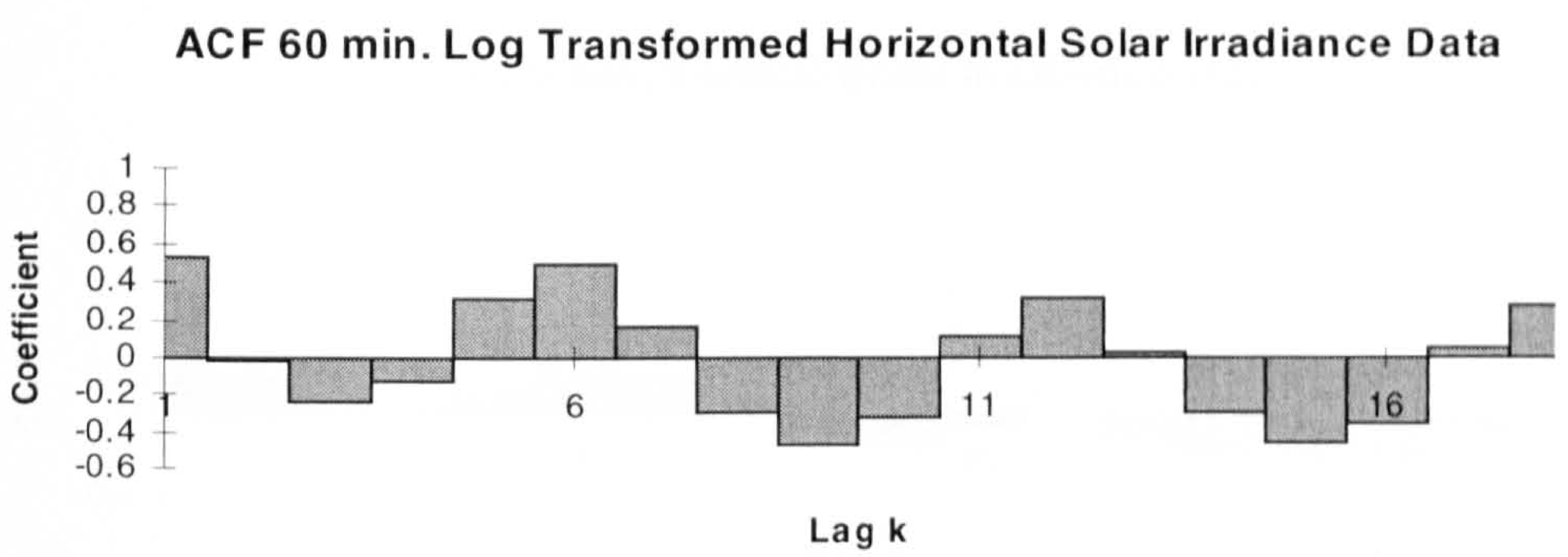


Figure 4.28.2 Log transformed Horizontal Solar Irradiance - 60 minute averages, DEC95_60

a)



b)



c)

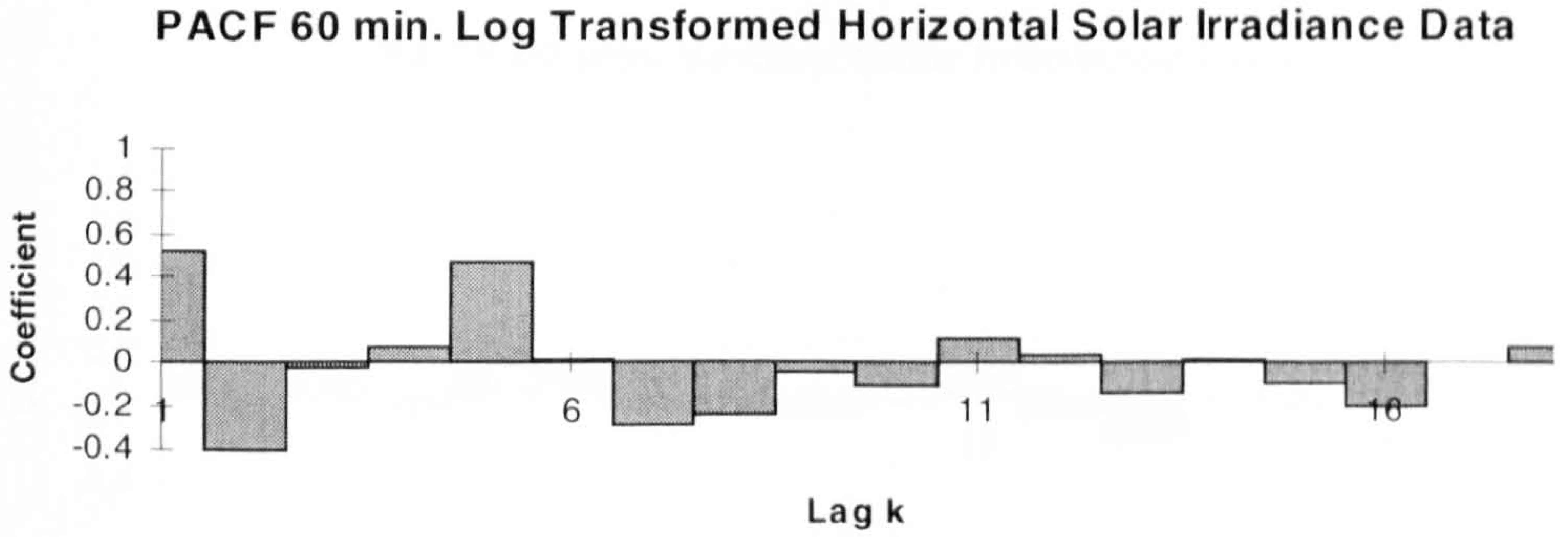
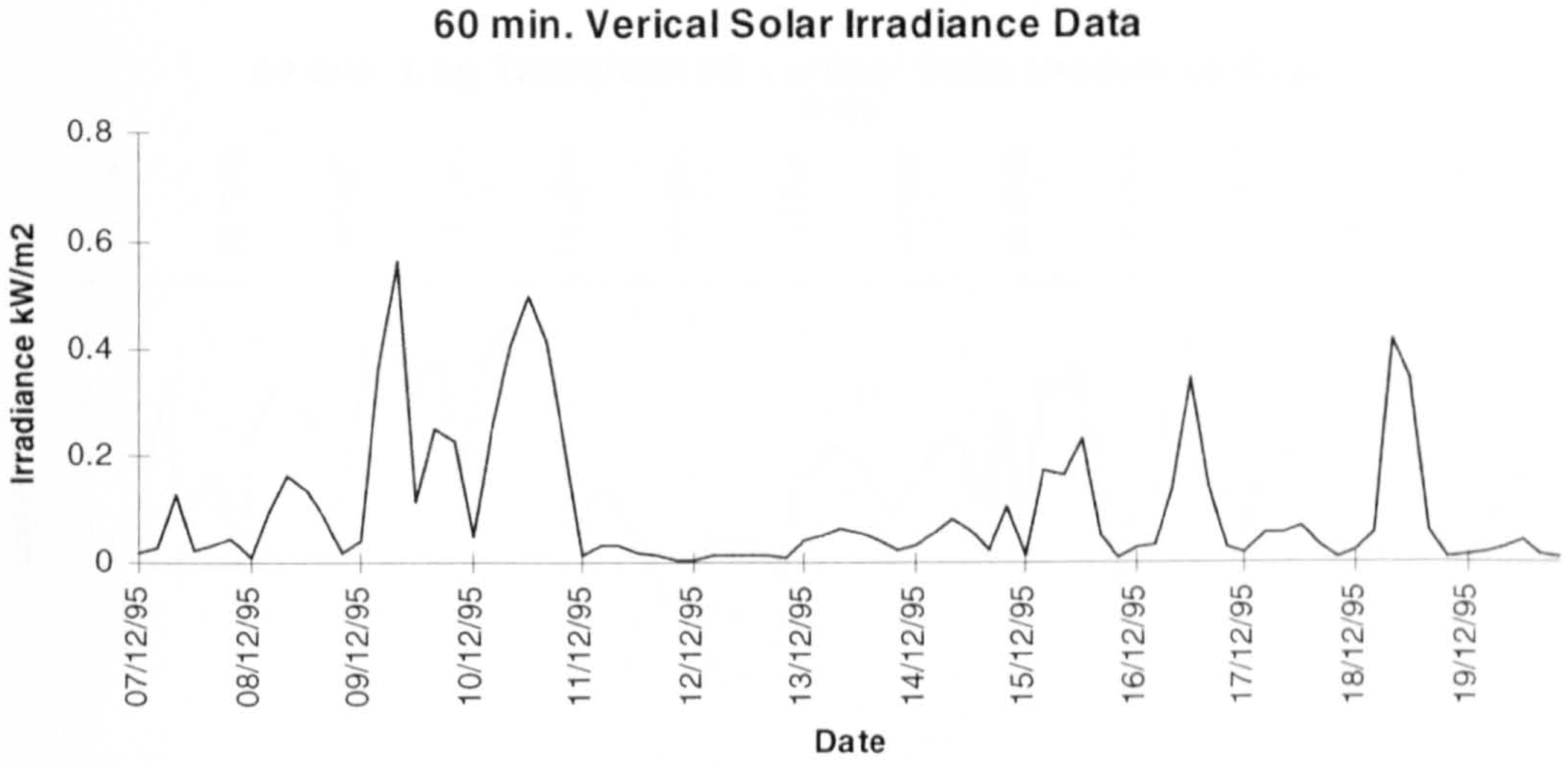
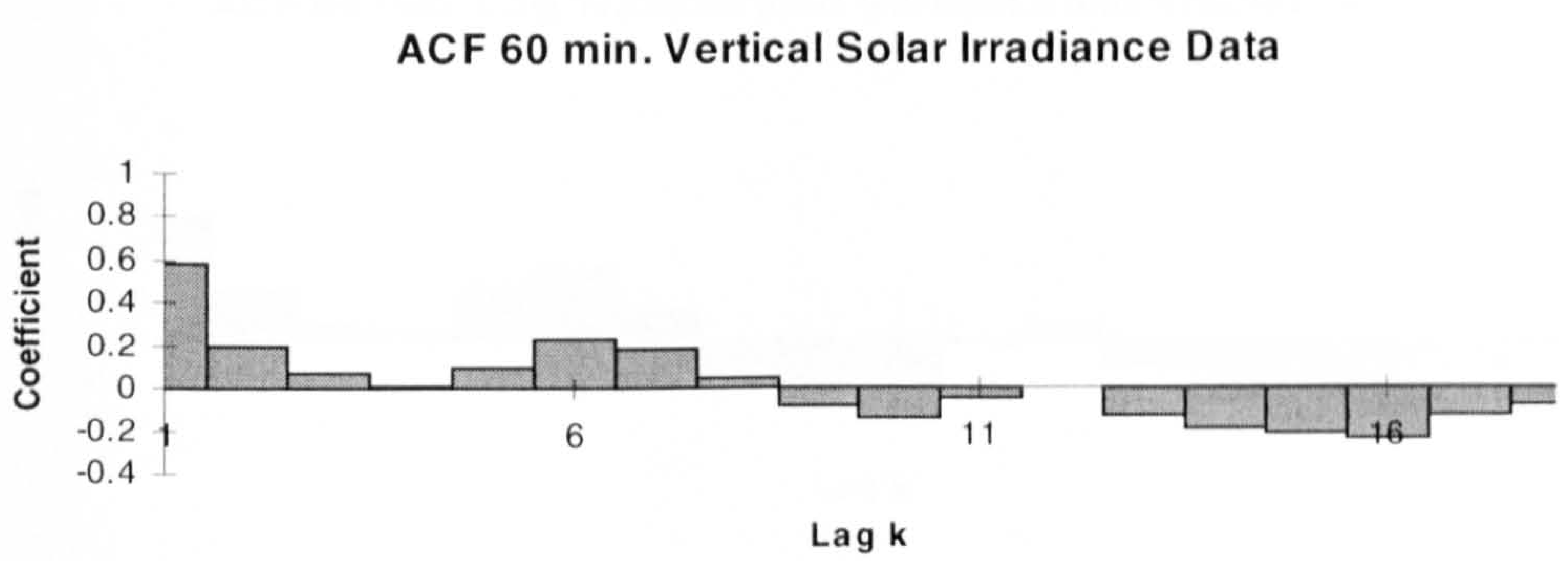


Figure 4.28.3 Vertical Solar Irradiance - 60 minute averages, DEC95_60

a)



b)



c)

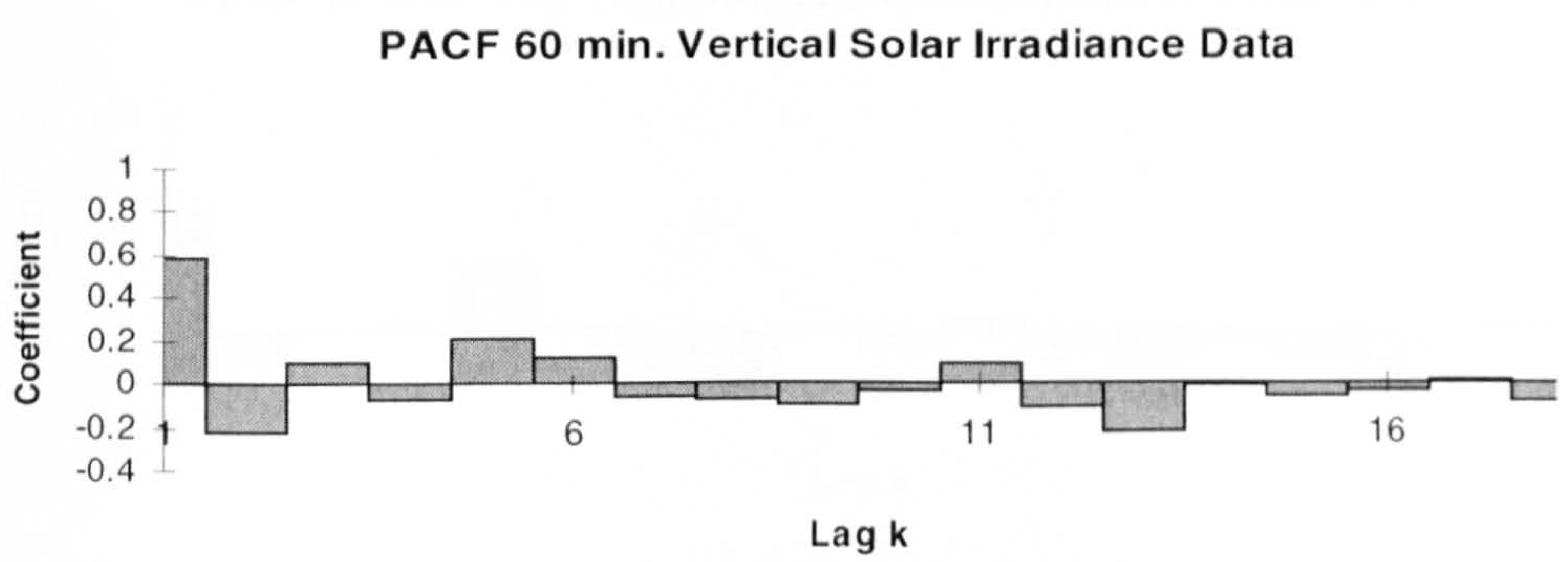
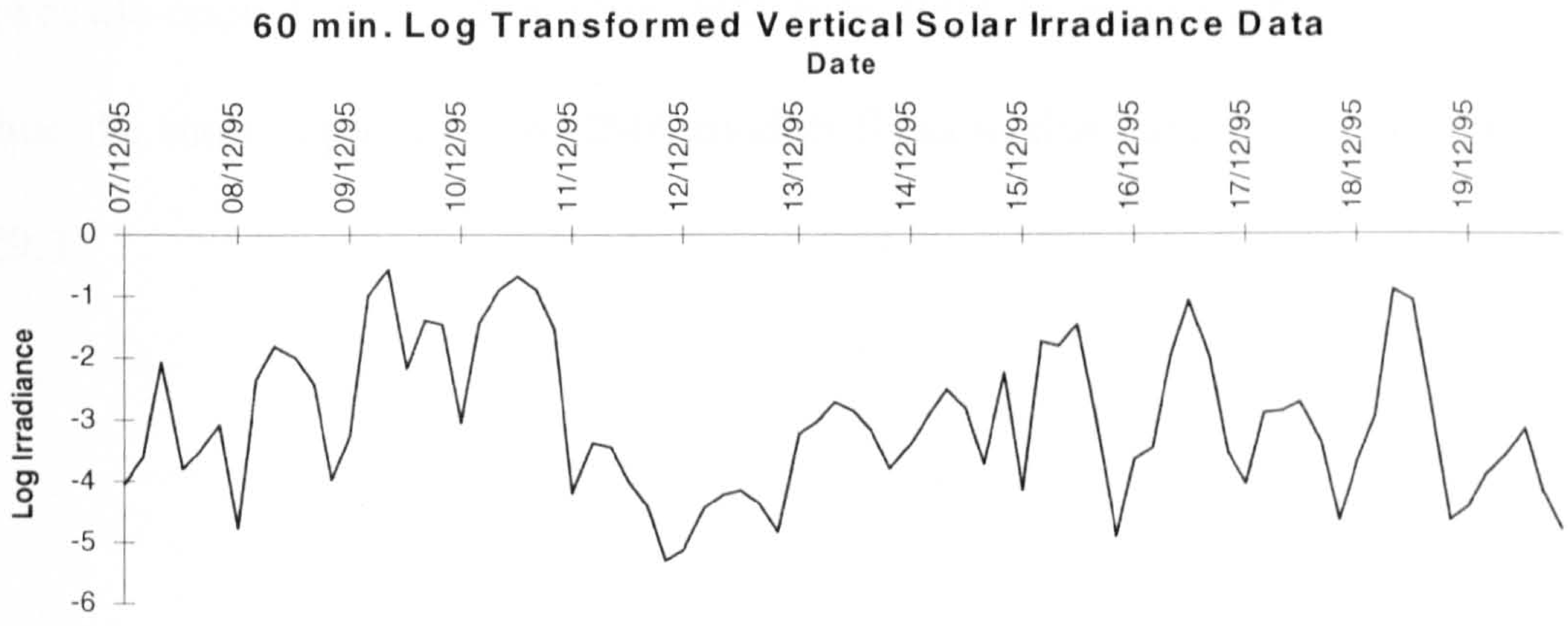
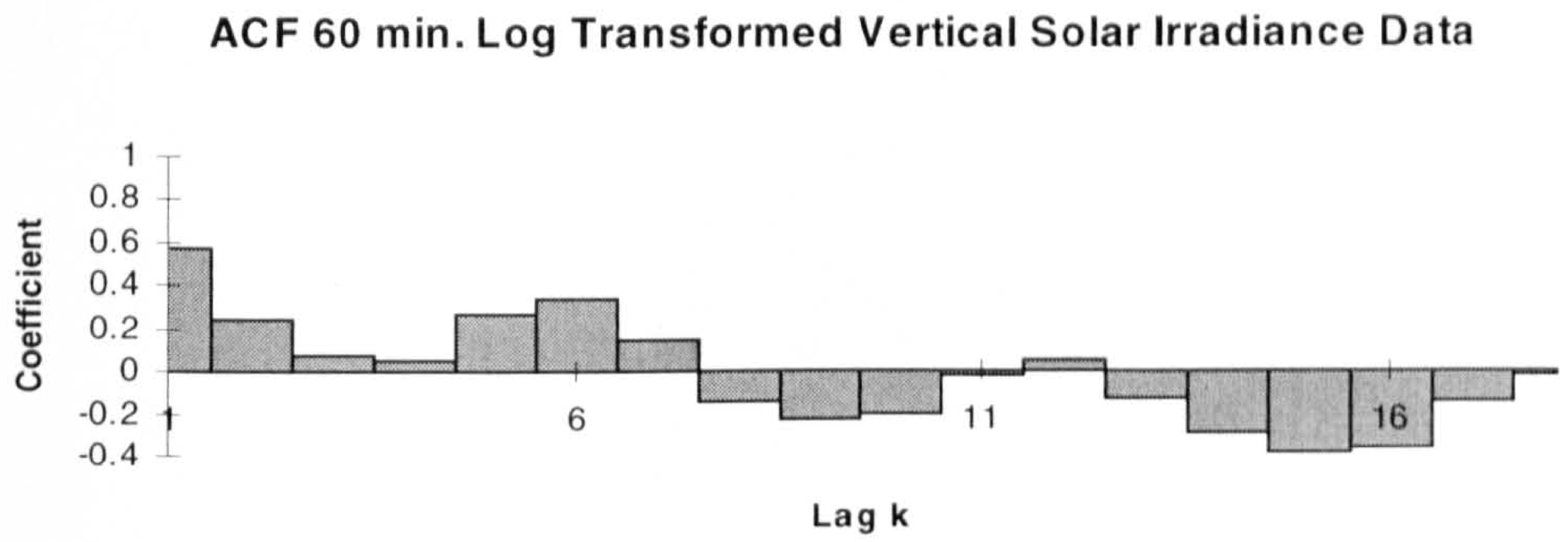


Figure 4.28.4 Log transformed Vertical Solar Irradiance - 60 minute averages, DEC95_60

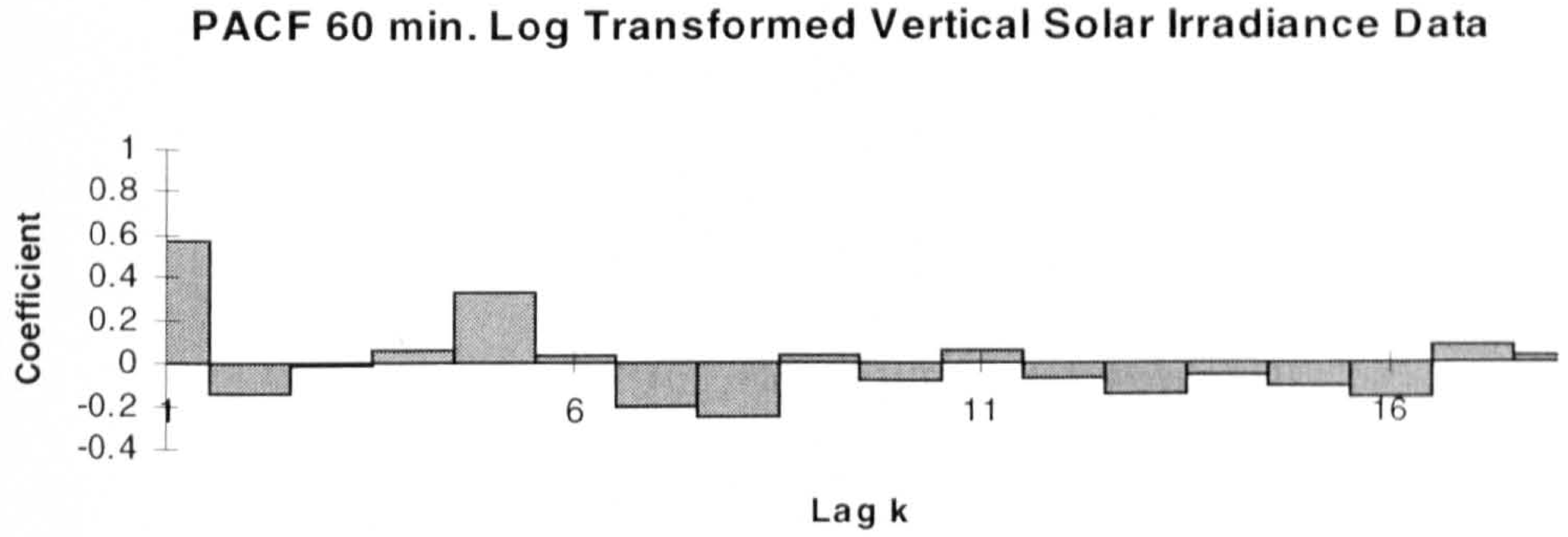
a)



b)



c)



4.29. Summary of Results

The following tables Table 4.29.1 and Table 4.29.2 summarise the lag 1 and lag k autocorrelations obtained for 10, 20, 30 and 60 minute averaged data recorded at Newcastle-upon-Tyne, in December 1993, June 1994, December 1994 and June 1995. While the most appropriate ARIMA models fitted to this data are detailed in Table 4.29.3.

Table 4.29.1 Lag 1 and lag k Autocorrelation Coefficients of Horizontal and Vertical solar irradiance data

	Original				First Differenced			
	lag 1		lag k		lag 1		lag k	
Data set	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert
DEC93_10	0.925	0.913	0.442	0.219	0.115	0.086	0.100	0.020
DEC93_20	0.864	0.848	0.458	0.230	0.146	0.001	0.216	0.018
DEC93_30	0.793	0.792	0.449	0.225	0.193	0.049	0.264	0.050
DEC93_60	0.524	0.624	0.454	0.237	0.120	0.024	0.491	0.229
DEC94_10	0.911	0.927	0.292	0.014	0.019	0.126	0.010	0.012
DEC94_20	0.844	0.862	0.297	0.011	-0.112	-0.039	0.062	0.004
DEC94_30	0.821	0.817	0.319	0.018	0.107	0.013	0.202	0.052
DEC94_60	0.636	0.665	0.331	0.023	0.089	-0.045	0.337	0.093
DEC94_10	0.866	0.884	0.310	0.056	-0.050	-0.085	0.007	0.046
DEC94_20	0.796	0.844	0.328	0.056	-0.078	-0.015	0.143	0.091
DEC94_30	0.784	0.818	0.336	0.047	0.263	0.188	0.255	0.085
DEC94_60	0.525	0.653	0.347	0.046	0.191	0.090	0.444	0.166
DEC95_10	0.888	0.883	0.318	0.173	0.016	-0.058	0.081	0.042
DEC95_20	0.819	0.831	0.353	0.178	0.116	0.220	0.097	-0.005
DEC95_30	0.730	0.725	0.365	0.179	0.055	0.052	0.138	-0.036
DEC95_60	0.540	0.583	0.411	0.238	0.140	-0.036	0.428	0.222
JUN94_10	0.807	0.850	0.263	0.316	-0.196	-0.165	-0.063	-0.054
JUN94_20	0.783	0.823	0.289	0.339	-0.218	-0.180	-0.027	0.003
JUN94_30	0.780	0.818	0.314	0.359	-0.170	-0.118	-0.104	0.139
JUN94_60	0.708	0.749	0.342	0.383	-0.127	-0.036	0.230	0.209
JUN94_10	0.881	0.910	0.248	0.300	-0.223	-0.203	0.014	-0.011
JUN94_20	0.873	0.903	0.264	0.315	-0.181	-0.160	0.011	0.003
JUN94_30	0.861	0.893	0.275	0.325	-0.084	-0.053	0.100	0.092
JUN94_60	0.820	0.852	0.287	0.338	0.174	0.347	0.252	0.296
JUN95_10	0.837	0.841	0.283	0.265	-0.173	-0.192	0.017	0.036
JUN95_20	0.808	0.817	0.308	0.286	-0.304	-0.316	0.043	0.053
JUN95_30	0.814	0.831	0.322	0.299	-0.159	-0.105	0.044	0.063
JUN95_60	0.745	0.749	0.358	0.324	0.049	0.071	0.140	0.124

Table 4.29.2 Lag 1 and lag k Autocorrelation Coefficients of Log Transformed Horizontal and Vertical solar irradiance data

	Original				First Differenced			
	lag 1		lag k		lag 1		lag k	
Data set	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert
DEC93_10	0.925	0.928	0.600	0.333	0.213	0.171	0.386	0.200
DEC93_20	0.843	0.859	0.609	0.333	0.186	0.151	0.470	0.248
DEC93_30	0.743	0.775	0.607	0.328	0.144	0.054	0.543	0.297
DEC93_60	0.384	0.537	0.613	0.322	-0.076	-0.132	0.699	0.400
DEC94_10	0.915	0.923	0.364	0.207	0.077	0.089	0.163	0.115
DEC94_20	0.838	0.851	0.365	0.205	-0.010	-0.088	0.228	0.122
DEC94_30	0.776	0.799	0.377	0.214	0.014	-0.062	0.304	0.122
DEC94_60	0.605	0.659	0.348	0.201	-0.034	-0.156	0.294	0.057
DEC94_10	0.905	0.900	0.308	0.112	0.097	0.002	0.114	0.120
DEC94_20	0.819	0.832	0.311	0.098	0.071	-0.037	0.220	0.086
DEC94_30	0.759	0.791	0.309	0.078	0.162	0.088	0.317	0.067
DEC94_60	0.511	0.595	0.284	0.065	-0.001	-0.066	0.426	0.176
DEC95_10	0.899	0.898	0.454	0.276	0.056	0.035	0.128	0.062
DEC95_20	0.835	0.831	0.469	0.281	0.193	0.149	0.237	0.016
DEC95_30	0.757	0.740	0.477	0.288	0.163	0.031	0.284	0.022
DEC95_60	0.525	0.580	0.497	0.340	0.114	-0.089	0.563	0.305
JUN94_10	0.871	0.913	0.327	0.453	-0.050	-0.011	-0.021	-0.024
JUN94_20	0.823	0.875	0.354	0.476	-0.119	-0.054	0.033	0.011
JUN94_30	0.800	0.854	0.373	0.502	-0.115	-0.053	0.115	0.150
JUN94_60	0.714	0.784	0.396	0.527	0.005	0.139	0.215	0.316
JUN94_10	0.921	0.952	0.350	0.425	-0.075	-0.007	0.075	0.035
JUN94_20	0.889	0.926	0.361	0.435	-0.020	0.062	0.083	0.105
JUN94_30	0.861	0.903	0.370	0.443	0.120	0.215	0.188	0.236
JUN94_60	0.747	0.808	0.374	0.450	0.051	0.218	0.300	0.386
JUN95_10	0.898	0.915	0.424	0.449	-0.051	-0.024	0.007	0.012
JUN95_20	0.857	0.873	0.444	0.466	-0.120	-0.105	0.053	0.067
JUN95_30	0.841	0.857	0.465	0.485	-0.032	0.006	0.068	0.065
JUN95_60	0.751	0.772	0.504	0.524	0.102	0.142	0.286	0.298

Table 4.29.3 Appropriate ARIMA models for a) Horizontal, b) Log Transformed Horizontal, c) Vertical, d) Log Transformed Vertical averaged data

a)

	model	AR1	AR2	AR3	AR4	SAR	Const	%
10 MIN								
DEC93	(2,1,0)(1,0,0)40	0.1080	-0.5490			0.0920		86
DEC94	(2,1,0)(1,0,0)36	0.0192	-0.1920			0.0353		83
DEC94	(2,1,0)(1,0,0)36	-0.0685	-0.1749			0.0478		74
DEC95	(2,1,0)(1,0,0)36	0.0127	0.0126			0.0819		78
JUN94	(4,1,0)	-0.2651	-0.3019	-0.0761	-0.1086			66
JUN94	(4,1,0)	-0.2869	-0.2234	-0.1128	-0.1052			79
JUN95	(4,1,0)	-0.2751	-0.3082	-0.2013	-0.1025			71
20 MIN								
DEC93	(1,0,0)(1,0,0)40	0.8302				0.2644	0.0086	76
DEC94	(1,0,0)(1,0,0)36	0.8429				0.0893	0.0087	72
DEC94	(1,0,0)(1,0,0)36	0.7920				0.1765	0.0134	64
DEC95	(1,0,0)(1,0,0)36	0.8116				0.1452	0.0089	68
JUN94	(2,1,0)	-0.2535	-0.1609					60
JUN94	(2,1,0)	-0.2004	-0.1072					76
JUN95	(2,1,0)	-0.3320	-0.0902					66
30 MIN								
DEC93	(1,0,0)(1,0,0)40	0.7813				0.3241	0.0102	66
DEC94	(1,0,0)(1,0,0)36	0.8182				0.2328	0.0083	70
DEC94	(1,0,0)(1,0,0)36	0.7799				0.2976	0.0119	65
DEC95	(1,0,0)(1,0,0)36	0.7037				-0.2945	0.0219	56
JUN94	(1,0,0)(1,0,0)28	0.7678				0.1646	0.0679	62
JUN94	(1,0,0)(1,0,0)28	0.8596				0.1327	0.0427	75
JUN95	(1,0,0)(1,0,0)28	0.8085				0.0821	0.0395	67
60 MIN								
DEC93	(1,0,0)(1,0,0)40	0.5794				0.5472	0.0139	46
DEC94	(1,0,0)(1,0,0)36	0.6486				0.3575	0.0134	47
DEC94	(1,0,0)(1,0,0)36	0.5752				0.4864	0.0171	42
DEC95	(1,0,0)(1,0,0)36	0.5686				0.4917	0.0119	44
JUN94	(1,0,0)(1,0,0)14	0.7227				0.3218	0.0347	60
JUN94	(1,0,0)(1,0,0)14	0.8235				0.2930	0.0431	70
JUN95	(1,0,0)(1,0,0)14	0.7158				0.2091	0.0508	57

b)

	model	AR1	AR2	AR3	AR4	SAR	Const	%
10 MIN								
DEC93	(2,1,0)(1,0,0)40	0.1850	-0.0854			0.4083		88
DEC94	(2,1,0)(1,0,0)36	0.0576	-0.0887			0.1726		84
DEC94	(2,1,0)(1,0,0)36	0.0768	-0.1044			0.1488		82
DEC95	(2,1,0)(1,0,0)36	0.0390	-0.0120			0.1327		81
JUN94	(4,1,0)	-0.0811	-0.2296	-0.0710	-0.1176			76
JUN94	(4,1,0)	-0.0873	-0.0988	-0.0677	0.0128			85
JUN95	(4,1,0)	-0.0851	-0.1982	-0.0972	-0.1022			80
20 MIN								
DEC93	(1,0,0)(1,0,0)40	0.8082				0.5418	-0.2681	79
DEC94	(1,0,0)(1,0,0)36	0.8368				0.2737	-0.3780	73
DEC94	(1,0,0)(1,0,0)36	0.8115				0.2956	-0.3671	70
DEC95	(1,0,0)(1,0,0)36	0.8268				0.3340	-0.3630	74
JUN94	(2,1,0)	-0.1382	-0.1532					60
JUN94	(2,1,0)	-0.0200	-0.0051					79
JUN95	(2,1,0)	-0.1322	-0.1031					72
30 MIN								
DEC93	(1,0,0)(1,0,0)40	0.7122				0.6153	-0.3308	71
DEC94	(1,0,0)(1,0,0)36	0.7788				0.3572	-0.4546	66
DEC94	(1,0,0)(1,0,0)36	0.7731				0.4277	-0.3607	64
DEC95	(1,0,0)(1,0,0)36	0.7363				0.3841	-0.5081	64
JUN94	(1,0,0)(1,0,0)28	0.7809				0.1874	-0.2322	65
JUN94	(1,0,0)(1,0,0)28	0.8665				0.2393	-0.1400	77
JUN95	(1,0,0)(1,0,0)28	0.8269				0.1271	-0.2663	71
60 MIN								
DEC93	(1,0,0)(1,0,0)40	0.5213				0.7411	-0.3562	56
DEC94	(1,0,0)(1,0,0)36	0.6058				0.3447	-0.8137	43
DEC94	(1,0,0)(1,0,0)36	0.6164				0.5165	-0.5056	40
DEC95	(1,0,0)(1,0,0)36	0.6170				0.6511	-0.4165	55
JUN94	(1,0,0)(1,0,0)14	0.6882				0.3410	0.0720	55
JUN94	(1,0,0)(1,0,0)14	0.7507				0.3812	-0.2094	64
JUN95	(1,0,0)(1,0,0)14	0.7043				0.3703	-0.3215	62

c)

	model	AR1	AR2	AR3	AR4	SAR	Const	%
10 MIN								
DEC93	(2,1,0)(1,0,0)40	0.0958	-0.1268			0.0224		83
DEC94	(2,1,0)(1,0,0)36	0.1507	-0.1915			0.0273		86
DEC94	(2,1,0)(1,0,0)36	-0.1017	-0.1447			0.0594		77
DEC95	(2,1,0)(1,0,0)36	-0.0514	0.0875			0.0426		77
JUN94	(4,1,0)	-0.2227	-0.2648	-0.0758	-0.0656			73
JUN94	(4,1,0)	-0.2595	-0.2132	-0.1055	-0.1257			84
JUN95	(4,1,0)	-0.2972	-0.3069	-0.2055	-0.0804			72
20 MIN								
DEC93	(1,0,0)(1,0,0)40	0.8473				0.0403	0.0240	72
DEC94	(1,0,0)(1,0,0)36	0.8654				0.0058	0.0200	74
DEC94	(1,0,0)(1,0,0)36	0.8485				0.0940	0.0318	70
DEC95	(1,0,0)(1,0,0)36	0.8326				0.0132	0.0155	69
JUN94	(2,1,0)	-0.2055	-0.1410					67
JUN94	(2,1,0)	-0.1748	-0.0914					81
JUN95	(2,1,0)	-0.3308	-0.0481					67
30 MIN								
DEC93	(1,0,0)(1,0,0)40	0.7883				0.0800	0.0327	63
DEC94	(1,0,0)(1,0,0)36	0.8225				0.0514	0.0249	67
DEC94	(1,0,0)(1,0,0)36	0.8223				0.0923	0.0374	67
DEC95	(1,0,0)(1,0,0)36	0.7291				-0.0030	0.0256	52
JUN94	(1,0,0)(1,0,0)28	0.8050				0.2029	0.0288	68
JUN94	(1,0,0)(1,0,0)28	0.8906				0.1243	-0.0184	80
JUN95	(1,0,0)(1,0,0)28	0.8248				0.0996	0.0182	69
60 MIN								
DEC93	(1,0,0)(1,0,0)40	0.6258				0.2747	0.0485	42
DEC94	(1,0,0)(1,0,0)36	0.6763				0.0843	0.0494	44
DEC94	(1,0,0)(1,0,0)36	0.6711				0.1651	0.0647	43
DEC95	(1,0,0)(1,0,0)36	0.5857				0.2368	0.0290	36
JUN94	(1,0,0)(1,0,0)14	0.6717				0.3439	-0.2766	56
JUN94	(1,0,0)(1,0,0)14	0.8535				0.3444	0.0179	76
JUN95	(1,0,0)(1,0,0)14	0.7338				0.1787	0.0251	57

d)

	model	AR1	AR2	AR3	AR4	SAR	Const	%
10 MIN								
DEC93	(2,1,0)(1,0,0)40	0.1783	-0.0879			0.2129		87
DEC94	(2,1,0)(1,0,0)36	0.0977	-0.1456			0.1160		86
DEC94	(2,1,0)(1,0,0)36	0.0055	-0.1305			0.1542		80
DEC95	(2,1,0)(1,0,0)36	0.0355	0.0211			0.0685		80
JUN94	(4,1,0)	-0.0226	-0.2107	-0.0359	-0.0961			84
JUN94	(4,1,0)	-0.0087	-0.0781	-0.0144	0.0252			91
JUN95	(4,1,0)	-0.0462	-0.1990	-0.0717	-0.0755			84
20 MIN								
DEC93	(1,0,0)(1,0,0)40	0.8539				0.2849	-0.2928	76
DEC94	(1,0,0)(1,0,0)36	0.8550				0.1395	-0.3850	73
DEC94	(1,0,0)(1,0,0)36	0.8326				0.1047	-0.3227	69
DEC95	(1,0,0)(1,0,0)36	0.8390				0.0515	-0.4935	70
JUN94	(2,1,0)	-0.0619	-0.1362					76
JUN94	(2,1,0)	0.0600	0.0464					86
JUN95	(2,1,0)	-0.1129	-0.0727					75
30 MIN								
DEC93	(1,0,0)(1,0,0)40	0.7725				0.3365	-0.4121	64
DEC94	(1,0,0)(1,0,0)36	0.8061				0.1450	-0.5109	65
DEC94	(1,0,0)(1,0,0)36	0.7916				0.0823	-0.4033	62
DEC95	(1,0,0)(1,0,0)36	0.7448				0.0791	-0.7501	56
JUN94	(1,0,0)(1,0,0)28	0.8314				0.2303	-0.2706	75
JUN94	(1,0,0)(1,0,0)28	0.9026				0.2915	-0.1464	84
JUN95	(1,0,0)(1,0,0)28	0.8427				0.1299	-0.3407	74
60 MIN								
DEC93	(1,0,0)(1,0,0)40	0.5732				0.4127	-0.6445	39
DEC94	(1,0,0)(1,0,0)36	0.6676				0.0987	-0.8993	44
DEC94	(1,0,0)(1,0,0)36	0.6154				0.1807	-0.6387	36
DEC95	(1,0,0)(1,0,0)36	0.5885				0.3631	-0.8224	41
JUN94	(1,0,0)(1,0,0)14	0.7249				0.4807	-0.2944	69
JUN94	(1,0,0)(1,0,0)14	0.8043				0.4691	-0.2180	74
JUN95	(1,0,0)(1,0,0)14	0.7248				0.3900	-0.4118	65

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5. Results from Analysis of 1, 5 and 10 minute Instantaneous Solar Irradiance Data, with 5 and 10 minute Instantaneous Data compared with 5 and 10 minute Averaged Data

This chapter contains the results of the analysis of 1 minute, 5 minute and 10 minute instantaneous Solar Irradiance data recorded from 9th - 19th July 1994 and 7th - 19th December 1995. The analysis of 5 minute averaged and 10 minute averaged data is also included for comparisons to be made between the different sampling techniques and sampling frequencies. These data-sets are fully described in section 2.2.

In the analysis the Horizontal Solar Irradiance data, the Log Transformed Horizontal Solar Irradiance data, the Vertical Solar Irradiance data and the Log Transformed Vertical Solar Irradiance data were analysed separately for individual days. The days were divided into three groups, Good, Average and Overcast. A particular day was classified by the percentage sunshine received on that day. This percentage was calculated using Eq. 5.1 where the number of sunshine hours recorded on a particular day is available from the local Meteorological Office and the expected number of sunshine hours for a particular day is calculated using the formulae in Duffie and Beckmann [1980].

$$\%\ \text{sunshine} = \frac{\text{actual number of hours of sunshine}}{\text{expected number of hours of sunshine}} * 100$$

Eq. 5.1

A Good day was defined to have a percentage greater than 66%, an Average day to have a percentage greater than 33% but less than 66% and an Overcast day to have a percentage less than 33%.

The daily percentage sunshine for the periods 9th - 19th July 1994 and 7th - 19th December 1995 are displayed in Table 4a and Table 4b respectively.

Table 5a Percentage Sunshine for the period 9th-19th July 1994.

Date	Actual sunshine hours	Expected sunshine hours	percentage %
9	1.7	16.5	10.3
10	1.2	16.5	7.2
11	3.8	16.5	23.0
12	7.4	16.5	44.8
13	9.4	16.5	57.0
14	8.1	16.5	49.0
15	6.2	16.5	37.5
16	8.9	16.5	54.0
17	12.3	16.5	74.5
18	4.9	16.5	29.7
19	12.0	16.5	72.7

Table 5b Percentage Sunshine for the period 7th-19th December 1995

Date	Actual sunshine hours	Expected sunshine hours	percentage %
7	0.0	7	0
8	0.8	7	11
9	4.0	7	57
10	4.0	7	57
11	0.0	7	0
12	0.0	7	0
13	0.1	7	1
14	1.2	7	17
15	1.7	7	24
16	1.7	7	24
1	0.6	7	8
18	0.9	7	12
19	0.0	7	0

5.1. One minute instantaneous data values - December 1995

The 1 minute instantaneous Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data for the two types of day, Average and Overcast, are displayed in Figure 5.1.1, Figure 5.1.2, Figure 5.1.3 and Figure 5.1.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.1.1(a), Table 5.1.2(a), Table 5.1.3(a) and Table 5.1.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.1.1(b), Table 5.1.2(b), Table 5.1.3(b) and Table 5.1.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.1.5.

Table 5.1.1 Horizontal Solar Irradiance - 1 minute intervals : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0493	0.0371	0.006	0.2127
8	0.0592	0.0358	0.0111	0.1551
9	0.0828	0.0462	0.0197	0.1688
10	0.1031	0.0494	0.0248	0.1755
11	0.0376	0.0211	0.0046	0.0979
12	0.0246	0.0098	0.0072	0.0523
13	0.0561	0.0247	0.0125	0.1201
14	0.0466	0.0229	0.0127	0.1995
15	0.0626	0.0486	0.0067	0.2338
16	0.0636	0.0477	0.111	0.2199
17	0.0486	0.0244	0.069	0.1713
18	0.0728	0.0723	0.0132	0.2877
19	0.0365	0.0204	0.009	0.0968
Overall	0.0572	0.0438	0.0046	0.2877

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.982	0.954	0.925	0.899	0.982	-0.316	0.085	0.049
8	0.980	0.959	0.940	0.923	0.980	-0.013	0.023	0.045
9	0.984	0.970	0.955	0.936	0.984	0.066	-0.068	-0.111
10	0.991	0.981	0.971	0.961	0.991	-0.000	-0.058	0.000
11	0.990	0.971	0.951	0.931	0.990	-0.373	0.015	0.075
12	0.977	0.942	0.907	0.872	0.977	-0.256	0.027	-0.021
13	0.974	0.923	0.859	0.793	0.974	-0.523	-0.013	0.037
14	0.828	0.760	0.595	0.515	0.828	0.236	-0.276	0.061
15	0.790	0.646	0.541	0.491	0.790	0.059	0.037	0.109
16	0.792	0.635	0.581	0.559	0.792	0.023	0.193	0.109
17	0.859	0.754	0.720	0.696	0.859	0.061	0.225	0.092
18	0.963	0.915	0.878	0.850	0.963	-0.168	0.162	0.033
19	0.992	0.977	0.957	0.934	0.992	-0.402	-0.192	-0.065

Table 5.1.2 Log Transformed Horizontal Solar Irradiance - 1 minute intervals : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.2402	0.668	-5.1160	-1.5479
8	-3.0415	0.6959	-4.5008	-1.8637
9	-2.6811	0.6508	-3.9571	-1.7790
10	-2.4175	0.5751	-3.6969	-1.7401
11	-3.4869	0.7133	-5.3817	-2.3238
12	-3.7976	0.4472	-4.9337	-2.9508
13	-2.9768	0.4437	-4.3820	-2.1194
14	-3.1634	0.4311	-4.3662	-1.6119
15	-3.0654	0.8057	-5.0056	-1.4533
16	-2.9761	0.6514	-4.5008	-1.5146
17	-3.1772	0.6021	-4.9762	-1.7643
18	-3.0044	0.8411	-4.3275	-1.2458
19	-3.4589	0.5542	-4.7105	-2.3351
Overall	-3.1144	0.7174	-5.3817	-1.2458

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.986	0.957	0.919	0.878	0.986	-0.556	-0.021	0.033
8	0.986	0.971	0.956	0.943	0.986	-0.032	-0.020	0.047
9	0.984	0.965	0.945	0.924	0.984	-0.082	-0.033	-0.047
10	0.985	0.970	0.953	0.937	0.985	-0.031	-0.031	0.001
11	0.987	0.971	0.954	0.937	0.987	-0.103	-0.040	0.001
12	0.973	0.941	0.908	0.876	0.973	-0.106	-0.031	0.011
13	0.968	0.909	0.840	0.769	0.968	-0.436	-0.037	0.008
14	0.934	0.856	0.751	0.665	0.934	-0.122	-0.255	0.129
15	0.925	0.865	0.815	0.785	0.925	0.059	0.056	0.118
16	0.894	0.789	0.719	0.669	0.894	-0.048	0.112	0.063
17	0.955	0.912	0.878	0.848	0.955	-0.001	0.083	0.027
18	0.979	0.951	0.927	0.903	0.979	-0.179	0.131	-0.064
19	0.985	0.966	0.942	0.918	0.985	-0.189	-0.108	-0.018

Table 5.1.3 Vertical Solar Irradiance - 1 minute intervals : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0447	0.0496	0.0030	0.3628
8	0.0856	0.0986	0.0056	0.3805
9	0.2601	0.2191	0.0160	0.6305
10	0.3049	0.1639	0.0242	0.5929
11	0.0193	0.0118	0.0030	0.0530
12	0.0115	0.0042	0.0039	0.0236
13	0.0456	0.0317	0.0084	0.2316
14	0.0589	0.0934	0.0063	0.7338
15	0.1071	0.1790	0.0039	0.7136
16	0.1178	0.1928	0.0078	0.7238
17	0.0395	0.0603	0.0041	0.6134
18	0.1511	0.2524	0.0065	0.8203
19	0.0206	0.0149	0.0050	0.0747
Overall	0.0975	0.1607	0.0030	0.8203

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.893	0.784	0.702	0.667	0.893	-0.068	0.078	0.178
8	0.948	0.903	0.864	0.832	0.948	0.037	0.036	0.070
9	0.985	0.973	0.960	0.943	0.985	0.096	-0.037	-0.139
10	0.988	0.975	0.961	0.948	0.988	-0.005	-0.079	0.032
11	0.990	0.973	0.953	0.935	0.990	-0.420	0.045	0.109
12	0.978	0.945	0.911	0.876	0.978	-0.255	0.002	-0.021
13	0.931	0.817	0.690	0.573	0.931	-0.379	-0.062	0.054
14	0.679	0.630	0.398	0.325	0.679	0.313	-0.222	0.001
15	0.646	0.446	0.304	0.251	0.646	0.049	-0.002	0.075
16	0.705	0.494	0.425	0.407	0.705	-0.005	0.157	0.106
17	0.473	0.131	0.097	0.098	0.473	-0.120	0.110	0.021
18	0.951	0.896	0.862	0.838	0.951	-0.082	0.193	0.063
19	0.993	0.979	0.959	0.934	0.993	-0.520	-0.226	-0.103

Table 5.1.4 Log Transformed Vertical Solar Irradiance - 1 minute intervals : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.5016	0.8666	-5.8091	-1.0139
8	-3.1260	1.2050	-5.1850	-0.9663
9	-1.9659	1.2727	-4.1352	-0.4612
10	-1.4459	0.8526	-3.7214	-0.5227
11	-4.1628	0.7039	-5.8091	-2.9375
12	-4.5437	0.4047	-5.5468	-3.7465
13	-3.2753	0.6037	-4.7795	-1.4627
14	-3.3268	0.8428	-5.0672	-0.3095
15	-3.2421	1.3847	-5.5468	-0.3374
16	-2.9797	1.1706	-4.8536	-0.3232
17	-3.6029	0.7969	-5.4968	-0.4887
18	-3.0368	1.4187	-5.0360	-0.1981
19	-4.0790	0.6069	-5.2983	-2.5943
Overall	-3.2530	1.2705	-5.8091	-0.1981

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.982	0.950	0.913	0.875	0.982	-0.359	-0.082	0.056
8	0.978	0.962	0.944	0.932	0.978	0.107	-0.015	0.103
9	0.987	0.971	0.956	0.940	0.987	-0.094	0.027	-0.074
10	0.986	0.972	0.956	0.941	0.986	-0.043	-0.033	0.008
11	0.989	0.976	0.961	0.946	0.989	-0.108	-0.070	0.018
12	0.976	0.945	0.912	0.881	0.976	-0.149	-0.038	0.017
13	0.968	0.906	0.829	0.747	0.968	-0.478	-0.091	0.022
14	0.916	0.836	0.731	0.659	0.916	-0.022	-0.200	0.142
15	0.900	0.822	0.768	0.741	0.900	0.061	0.096	0.144
16	0.882	0.778	0.712	0.667	0.882	0.005	0.110	0.079
17	0.870	0.771	0.727	0.700	0.870	0.055	0.189	0.097
18	0.977	0.951	0.932	0.913	0.977	-0.051	0.110	0.005
19	0.986	0.967	0.944	0.918	0.986	-0.210	-0.119	-0.069

Table 5.1.5 Summary information from fitted ARIMA models

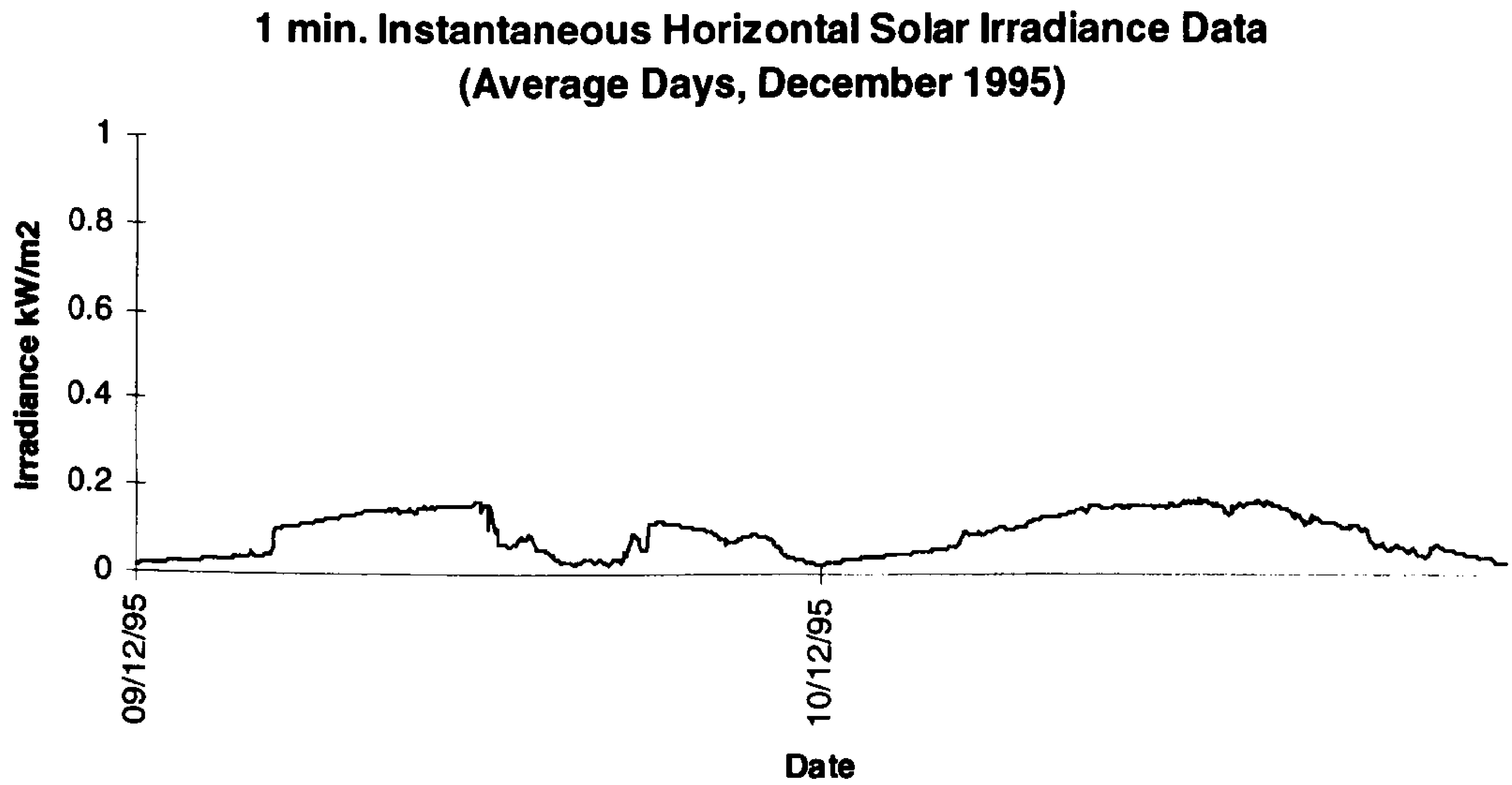
(a)

	1 minute instantaneous Horizontal Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(4,1,0)	97	(2,1,0)	99
8				
9	(3,1,0)	98	(1,1,0)	98
10	(2,1,0)	99	(2,1,0)	99
11	(2,1,0)	99	(2,1,0)	99
12	(2,1,0)	99	(1,1,0)	98
13	(2,1,0)	97	(2,1,0)	98
14	(4,1,0)	73	(4,1,0)	88
15	(4,1,0)	64	(4,1,0)	88
16	(4,1,0)	64	(4,1,0)	82
17	(4,1,0)	76	(2,1,0)	94
18	(4,1,0)	93	(2,1,0)	96
19	(2,1,0)	99	(2,1,0)	99

(b)

	1 minute instantaneous Vertical Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(3,1,0)	80	(4,1,0)	98
8	(1,0,0)	90	(3,1,0)	97
9	(3,1,0)	97	(3,1,0)	98
10	(2,1,0)	98	(2,1,0)	99
11	(2,1,0)	94	(3,1,0)	99
12	(2,1,0)	97	(1,1,0)	98
13	(4,1,0)	89	(4,1,0)	96
14	(4,1,0)	53	(4,1,0)	85
15	(4,1,0)	40	(4,1,0)	83
16	(4,1,0)	49	(4,1,0)	78
17	(4,1,0)	14	(4,1,0)	78
18	(4,1,0)	90	(2,1,0)	96
19	(2,1,0)	99	(2,1,0)	99

Figure 5.1.1 Horizontal Solar Irradiance for 1 minute instantaneous data



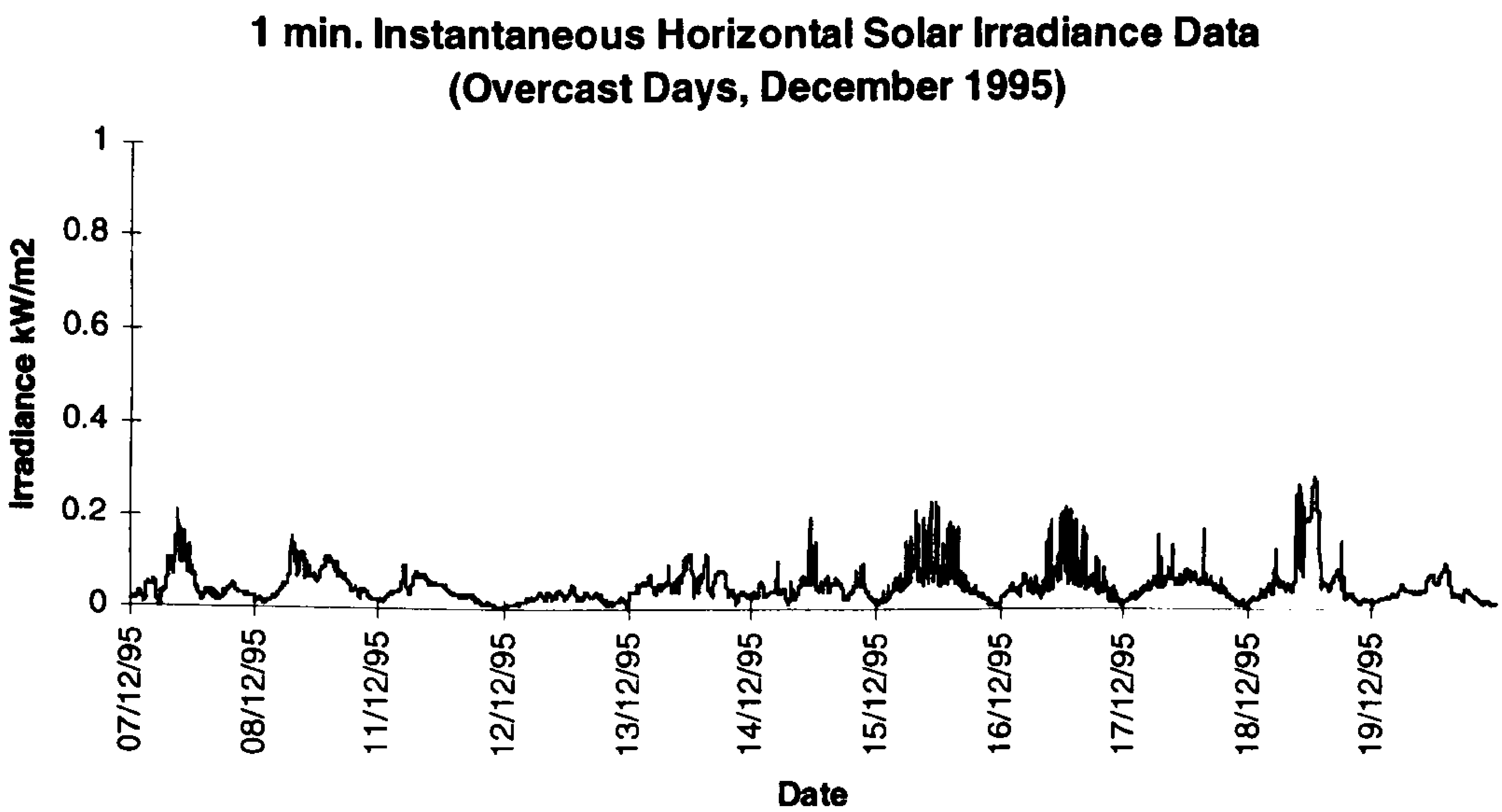
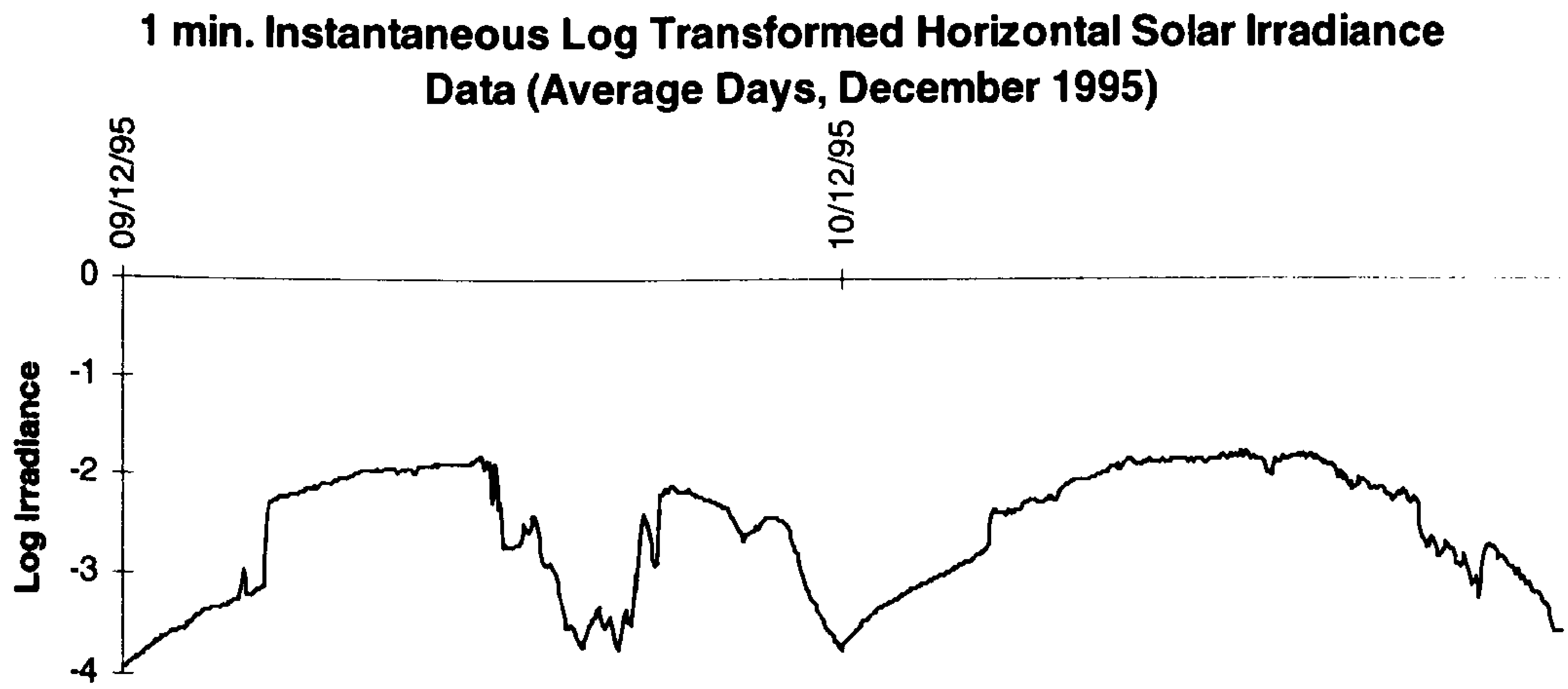


Figure 5.1.2 Log transformed Horizontal Solar Irradiance for 1 minute instantaneous data



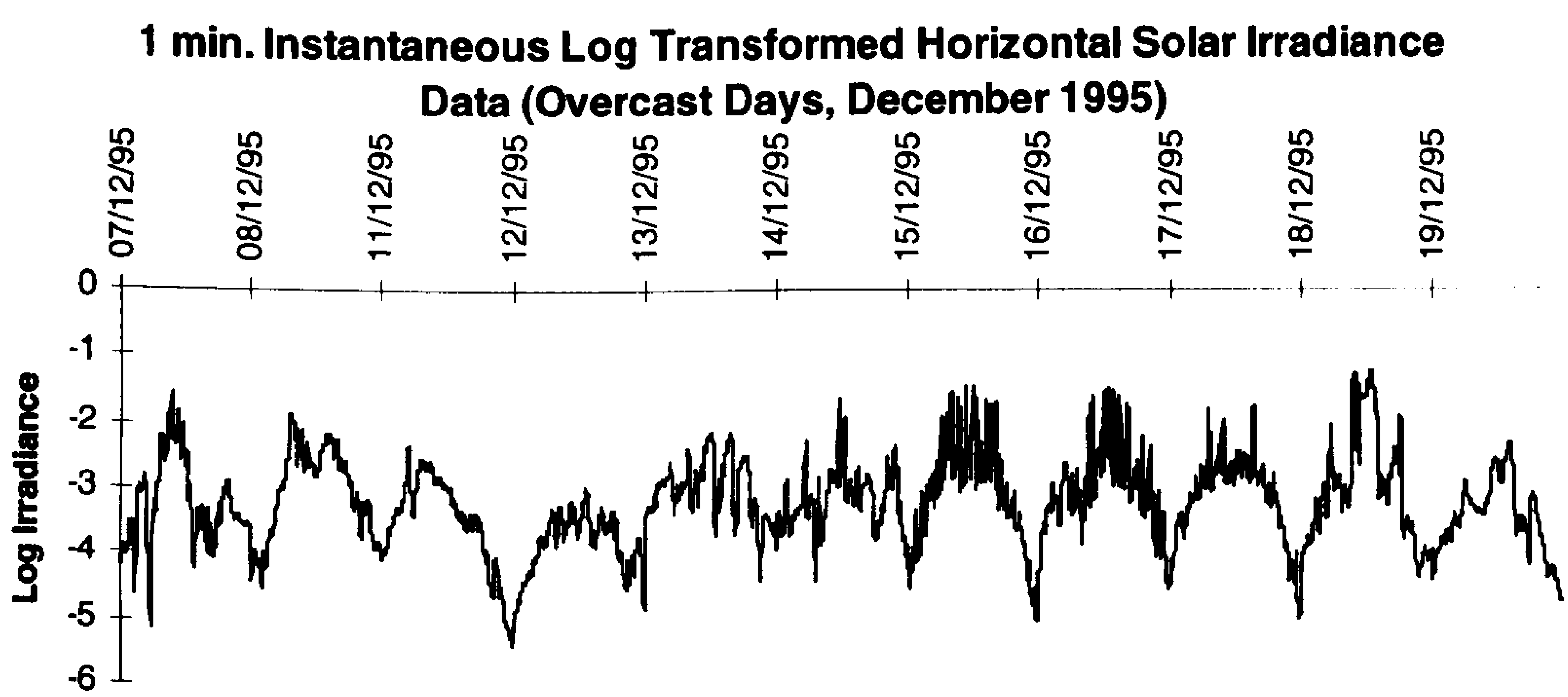
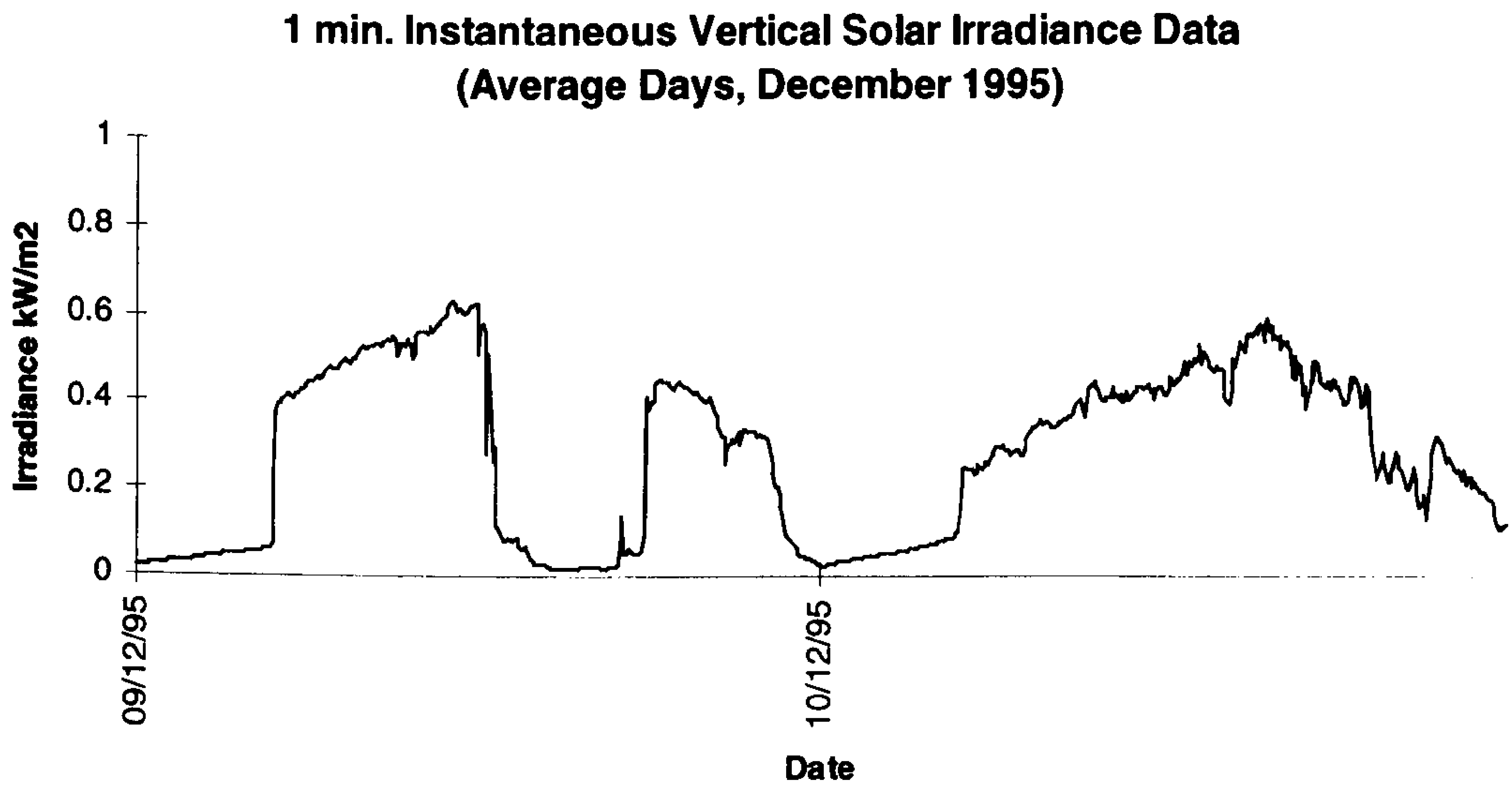


Figure 5.1.3 Vertical Solar Irradiance for 1 minute instantaneous data



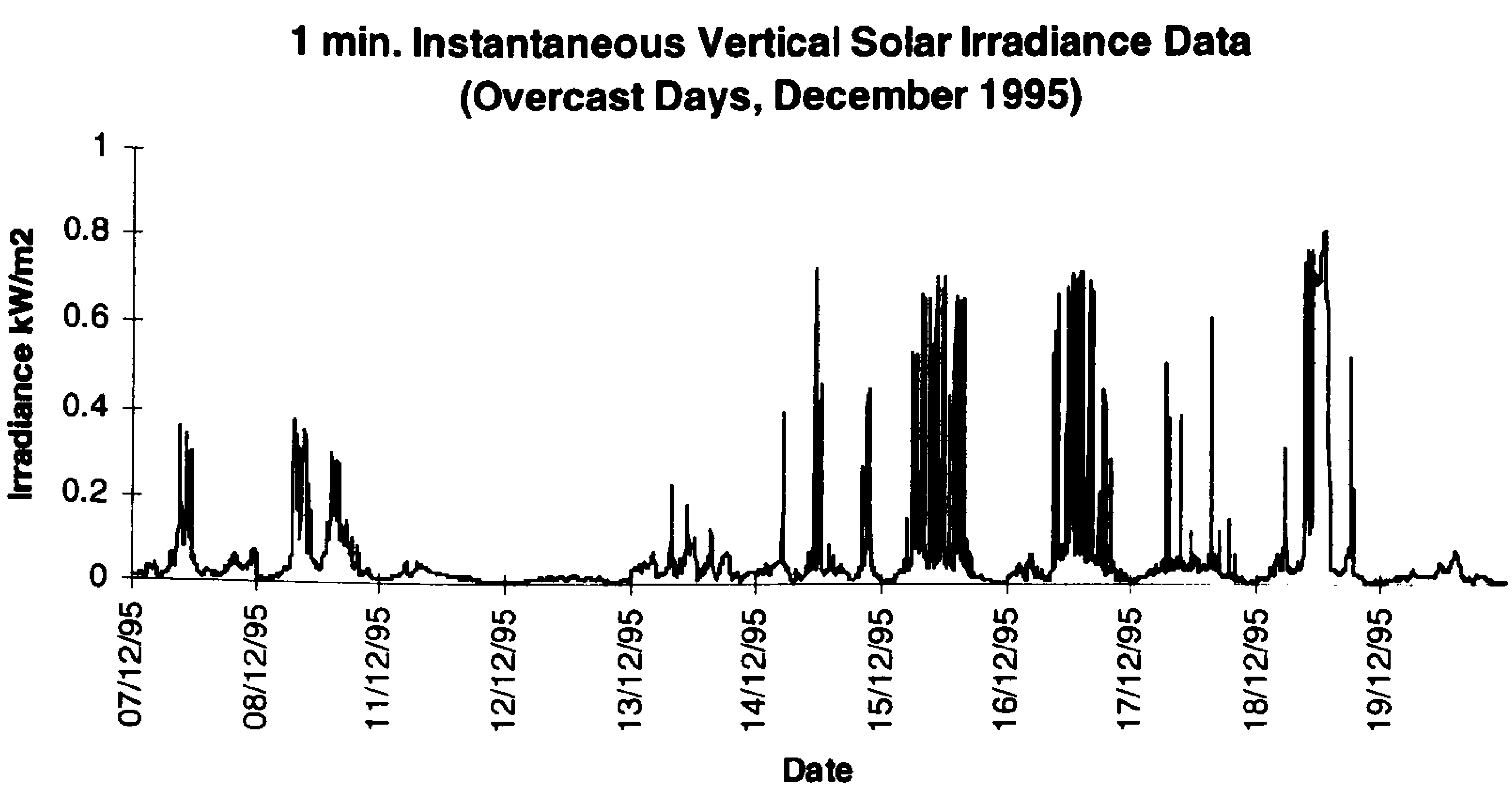
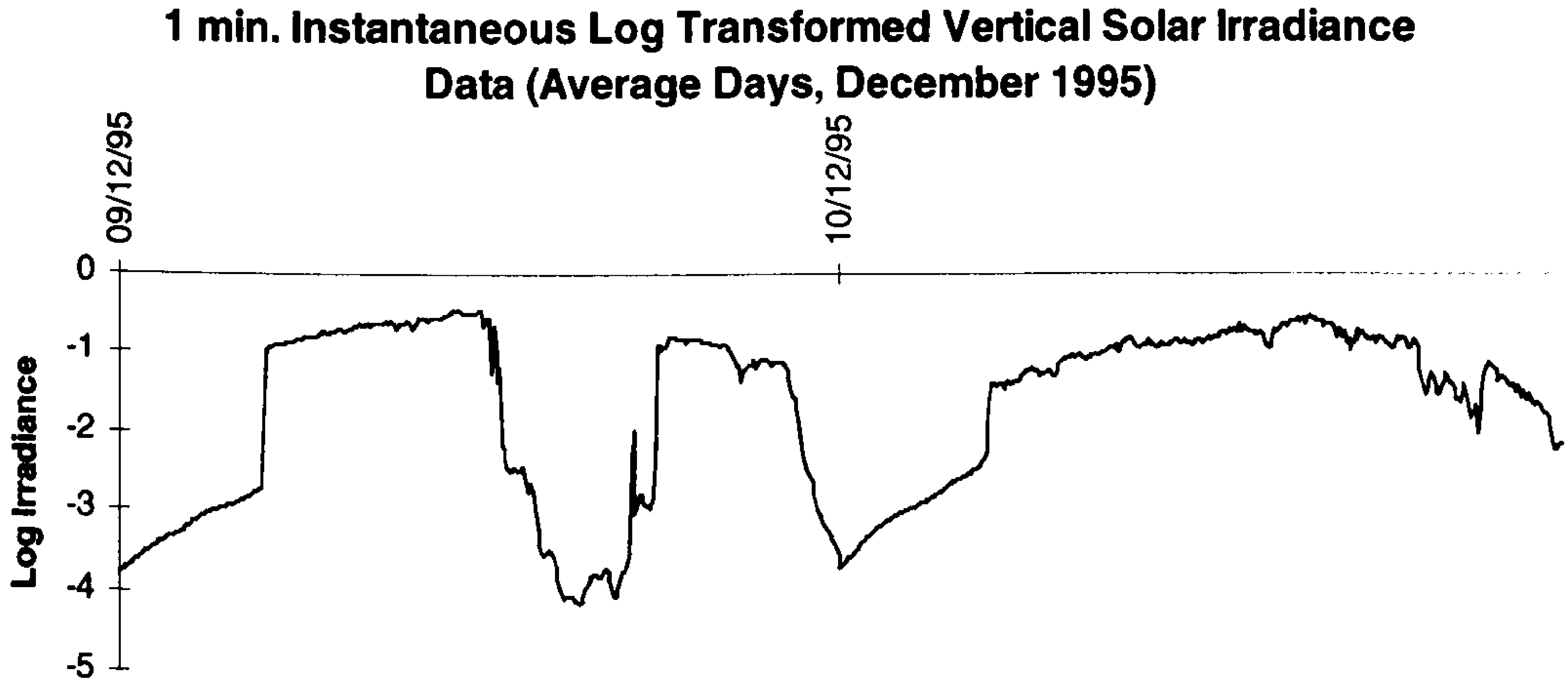
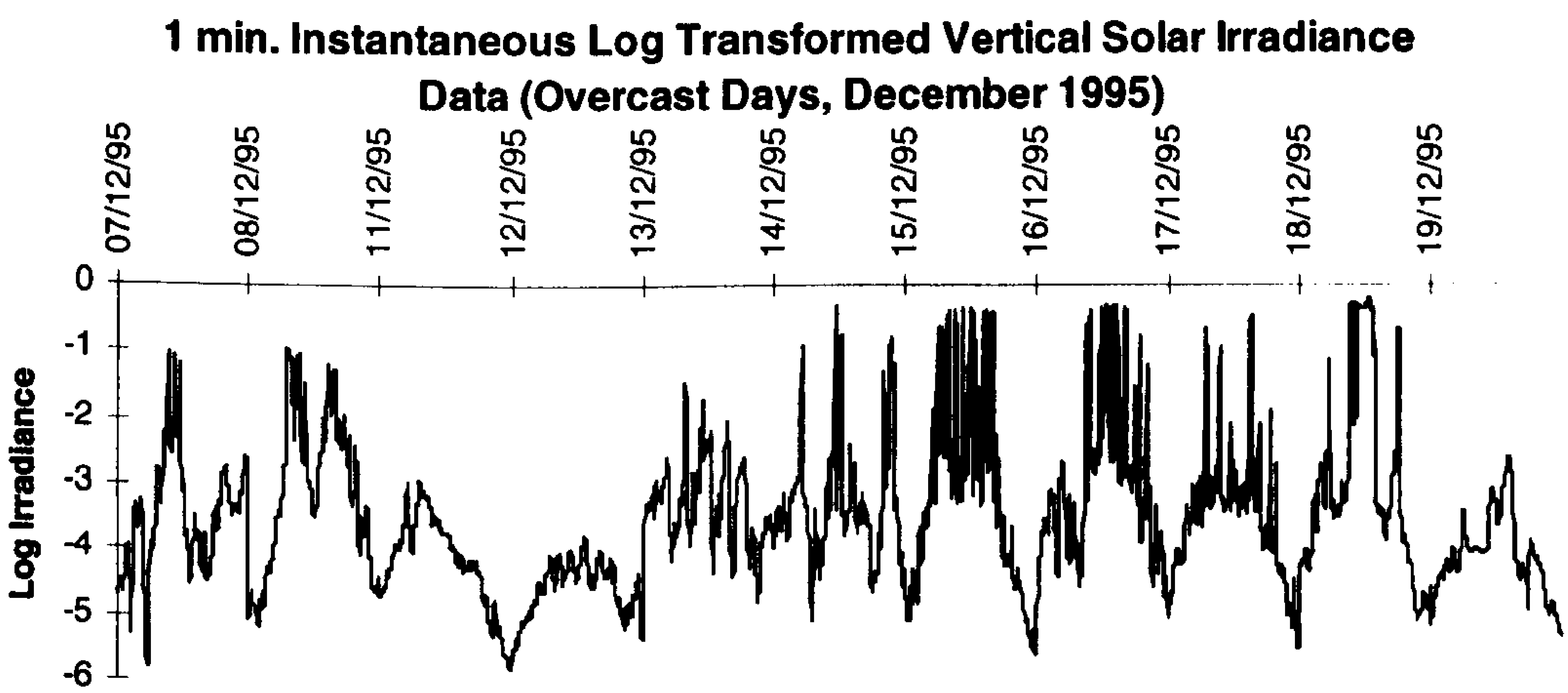


Figure 5.1.4 Log transformed Vertical Solar Irradiance for 1 minute instantaneous data





5.2. Five minute instantaneous - December 1995

The 5 minute instantaneous Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data are displayed in Figure 5.2.1, Figure 5.2.2, Figure 5.2.3 and Figure 5.2.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.2.1(a), Table 5.2.2(a), Table 5.2.3(a) and Table 5.2.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.2.1(b), Table 5.2.2(b), Table 5.2.3(b) and Table 5.2.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.2.5.

Table 5.2.1 Horizontal Solar Irradiance - 5 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0495	0.0387	0.0069	0.2127
8	0.0595	0.0365	0.0118	0.1544
9	0.0823	0.0462	0.0197	0.1688
10	0.1035	0.0497	0.0248	0.1699
11	0.0375	0.0208	0.0049	0.0863
12	0.0244	0.0100	0.0072	0.0507
13	0.0563	0.0252	0.0150	0.1201
14	0.0465	0.0219	0.0150	0.1486
15	0.0631	0.0512	0.0081	0.2333
16	0.0630	0.0472	0.0116	0.2199
17	0.0495	0.0267	0.0074	0.1713
18	0.0717	0.0700	0.0134	0.2843
19	0.0366	0.0204	0.0093	0.0968
Overall	0.0572	0.0438	0.0049	0.2843

b)

$2/\sqrt{72} = 0.236$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.831	0.761	0.610	0.491	0.831	0.228	-0.145	0.199
8	0.905	0.826	0.751	0.650	0.905	0.043	-0.019	-0.179
9	0.911	0.822	0.723	0.629	0.911	-0.043	-0.112	-0.024
10	0.950	0.902	0.853	0.802	0.950	-0.000	-0.029	-0.051
11	0.918	0.824	0.740	0.694	0.918	-0.127	0.025	0.190
12	0.843	0.683	0.533	0.475	0.843	-0.093	-0.062	0.224
13	0.730	0.467	0.255	0.111	0.730	-0.142	-0.067	-0.022
14	0.488	0.272	0.309	0.112	0.488	0.046	0.211	-0.161
15	0.572	0.348	0.396	0.412	0.572	0.030	0.276	0.130
16	0.628	0.443	0.418	0.473	0.628	0.081	0.185	0.230
17	0.624	0.519	0.522	0.509	0.624	0.213	0.230	0.149
18	0.808	0.717	0.587	0.503	0.808	0.182	-0.103	0.024
19	0.911	0.767	0.612	0.490	0.911	-0.366	-0.058	0.137

Table 5.2.2 Log Transformed Horizontal Solar Irradiance - 5 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.2396	0.6697	-4.9762	-1.5479
8	-3.0445	0.7145	-4.4397	-1.8682
9	-2.6875	0.6534	-3.9271	-1.7790
10	-2.4139	0.5794	-3.6969	-1.7725
11	-3.4823	0.7013	-5.3185	-2.4499
12	-3.8082	0.4585	-4.9337	-2.9818
13	-2.9743	0.4501	-4.1997	-2.1194
14	-3.1626	0.4348	-4.1997	-1.9065
15	-3.0647	0.8129	-4.8159	-1.4554
16	-2.9783	0.6413	-4.4568	-1.5146
17	-3.1661	0.6130	-4.9063	-1.7643
18	-3.0095	0.8379	-4.3125	-1.2577
19	-3.4559	0.5527	-4.6777	-2.3351
Overall	-3.1144	0.7173	-5.3185	-1.2577

b)

$2/\sqrt{72} = 0.236$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.835	0.677	0.540	0.443	0.835	-0.067	-0.025	0.046
8	0.931	0.866	0.802	0.730	0.931	-0.015	-0.018	-0.099
9	0.900	0.805	0.693	0.588	0.900	-0.032	-0.136	-0.035
10	0.919	0.853	0.793	0.736	0.919	0.059	0.008	-0.009
11	0.917	0.832	0.757	0.694	0.917	-0.059	0.021	0.024
12	0.862	0.739	0.620	0.552	0.862	-0.013	-0.055	0.129
13	0.701	0.459	0.286	0.189	0.701	-0.063	-0.023	0.027
14	0.563	0.353	0.301	0.155	0.563	0.052	0.122	-0.101
15	0.791	0.668	0.635	0.590	0.791	0.113	0.206	0.050
16	0.680	0.548	0.472	0.519	0.680	0.158	0.097	0.258
17	0.807	0.717	0.671	0.603	0.807	0.189	0.147	-0.008
18	0.864	0.760	0.677	0.612	0.864	0.053	0.036	0.041
19	0.897	0.780	0.665	0.570	0.897	-0.122	-0.051	0.030

Table 5.2.3 Vertical Solar Irradiance - 5 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0479	0.0641	0.0037	0.3628
8	0.0870	0.0998	0.058	0.3712
9	0.2577	0.2194	0.0165	0.6277
10	0.3065	0.1660	0.0242	0.5792
11	0.0193	0.0118	0.0030	0.0494
12	0.0114	0.0043	0.0039	0.0232
13	0.0467	0.0343	0.0106	0.1872
14	0.0583	0.0898	0.0076	0.4703
15	0.1111	0.1896	0.0045	0.7128
16	0.1128	0.1941	0.0078	0.7238
17	0.0445	0.0821	0.0045	0.6134
18	0.1467	0.2435	0.0067	0.8043
19	0.0206	0.0151	0.0052	0.0747
Overall	0.0977	0.1610	0.0030	0.8043

b)

$2/\sqrt{72} = 0.236$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.481	0.529	0.316	0.435	0.481	0.387	-0.039	0.222
8	0.802	0.696	0.607	0.440	0.802	0.148	0.036	-0.248
9	0.922	0.815	0.708	0.594	0.922	-0.232	-0.026	-0.119
10	0.933	0.881	0.835	0.786	0.933	0.084	0.025	-0.035
11	0.910	0.828	0.745	0.698	0.910	0.006	-0.052	0.156
12	0.847	0.696	0.551	0.492	0.847	-0.075	-0.069	0.216
13	0.510	0.196	0.066	-0.000	0.510	-0.088	0.033	-0.028
14	0.399	0.149	0.163	0.077	0.399	-0.012	0.128	-0.037
15	0.452	0.058	0.124	0.258	0.452	-0.184	0.229	0.138
16	0.463	0.210	0.267	0.382	0.463	-0.005	0.218	0.240
17	0.080	0.023	0.024	0.072	0.080	0.017	0.021	0.068
18	0.792	0.714	0.594	0.526	0.792	0.233	-0.069	0.038
19	0.905	0.729	0.535	0.380	0.905	-0.502	-0.008	0.153

Table 5.2.4 Log Transformed Vertical Solar Irradiance - 5 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.4970	0.9020	-5.5990	-1.0140
8	-3.1270	1.2350	-5.1500	-0.9910
9	-1.9700	1.271	-4.1040	-0.4660
10	-1.4480	0.8750	-3.7210	-0.5460
11	-4.1581	0.6974	-5.8091	-3.0078
12	-4.5489	0.4140	-5.5468	-3.7636
13	-3.2651	0.6203	-4.5469	-1.6756
14	-3.3273	0.8423	-4.8796	-0.7544
15	-3.2360	1.4040	-5.404	-0.3390
16	-3.0200	1.1470	-4.8540	-0.3230
17	-3.5853	0.8458	-5.4037	-0.4887
18	-3.0390	1.4110	-5.0060	-0.2180
19	-4.0826	0.6153	-5.2591	-2.5943
Overall	-3.2543	1.2730	-5.8091	-0.2178

b)

$2/\sqrt{72} = 0.236$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.811	0.676	0.529	0.454	0.811	0.053	-0.096	0.108
8	0.923	0.854	0.779	0.681	0.923	0.008	-0.075	-0.196
9	0.920	0.825	0.736	0.623	0.920	-0.136	-0.001	-0.224
10	0.924	0.861	0.802	0.744	0.924	0.046	0.004	-0.026
11	0.927	0.853	0.787	0.731	0.927	-0.039	0.015	0.028
12	0.864	0.746	0.625	0.560	0.864	-0.004	-0.076	0.150
13	0.659	0.337	0.107	0.011	0.659	-0.172	-0.072	0.028
14	0.612	0.405	0.314	0.151	0.612	0.048	0.078	-0.127
15	0.771	0.617	0.603	0.608	0.771	0.056	0.275	0.147
16	0.665	0.509	0.458	0.490	0.665	0.120	0.147	0.214
17	0.648	0.542	0.507	0.513	0.648	0.211	0.169	0.177
18	0.881	0.785	0.690	0.622	0.881	0.036	-0.036	0.065
19	0.880	0.738	0.604	0.503	0.880	-0.161	-0.036	0.059

Table 5.2.5 Summary information from fitted ARIMA models

(a)

	5 minute instantaneous Horizontal Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(1,1,0)	70	(1,0,0)	72
8	(1,0,0)	85		
9	(1,0,0)	87	(2,1,0)	88
10			(3,1,0)	96
11	(3,1,0)	89		
12	(3,1,0)	77	(3,1,0)	84
13	(1,0,0)	56	(1,0,0)	54
14	(2,1,0)	19	(2,1,0)	30
15	(2,1,0)	34	(2,1,0)	73
16	(1,0,0)	40	(3,1,0)	59
17	(1,0,0)	41	(2,1,0)	81
18	(1,1,0)	65	(1,1,0)	77
19	(3,1,0)	90	(3,1,0)	91

(b)

	5 minute instantaneous Vertical Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(3,1,0)	31	(1,0,0)	68
8	(1,1,0)	64	(3,1,0)	90
9	(1,1,0)	88	(3,1,0)	89
10				
11	(3,1,0)	86		
12	(3,1,0)	78	(3,1,0)	84
13	(1,0,0)	26	(3,1,0)	36
14	(1,0,0)	14	(2,1,0)	30
15	(3,1,0)	18	(3,1,0)	67
16	(4,1,0)	25	(3,1,0)	49
17	(3,1,0)		(3,1,0)	55
18	(1,1,0)	63	(1,1,0)	79
19	(3,1,0)	89	(3,1,0)	86

Figure 5.2.1 Horizontal Solar Irradiance for 5 minute instantaneous data

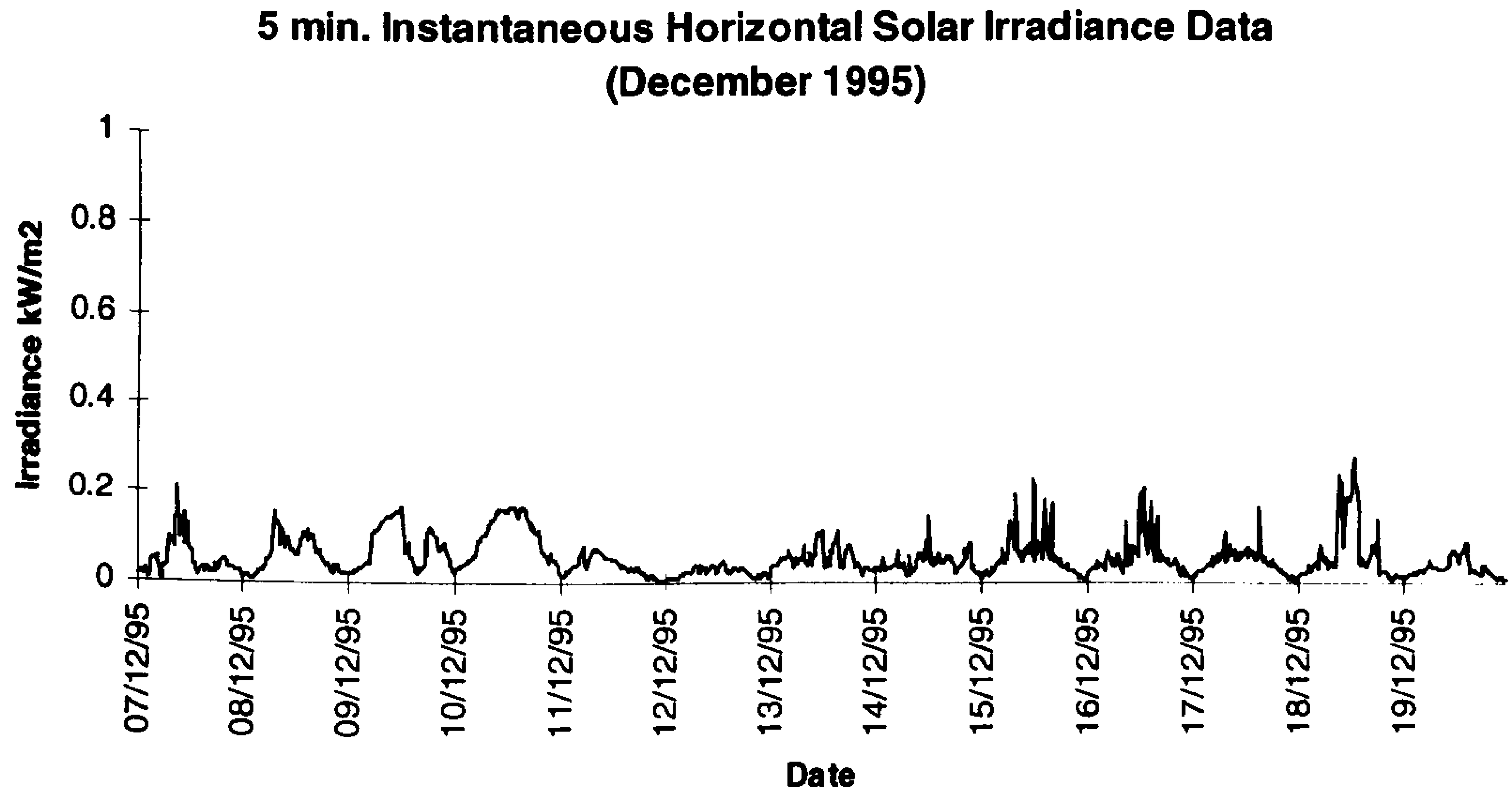


Figure 5.2.2 Log transformed Horizontal Solar Irradiance for 5 minute instantaneous data

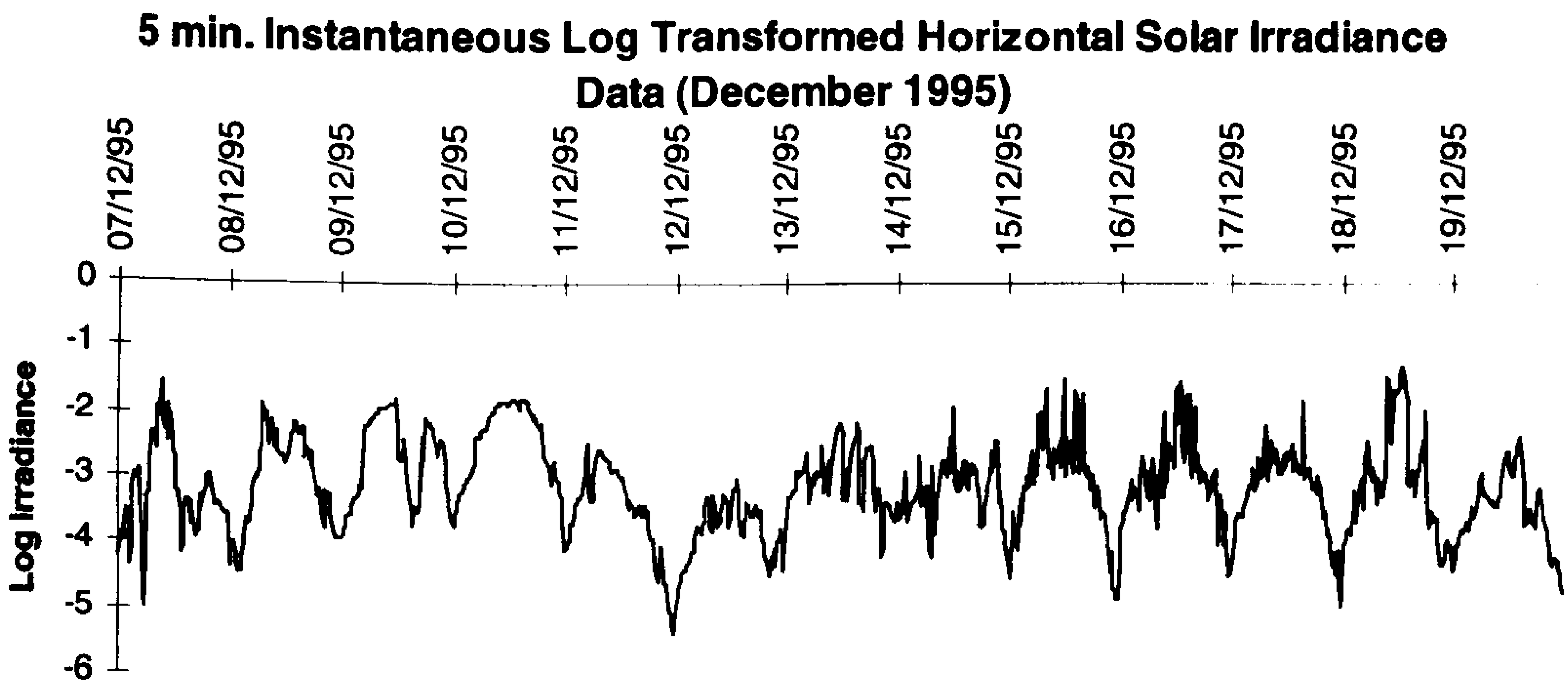


Figure 5.2.3 Vertical Solar Irradiance for 5 minute instantaneous data

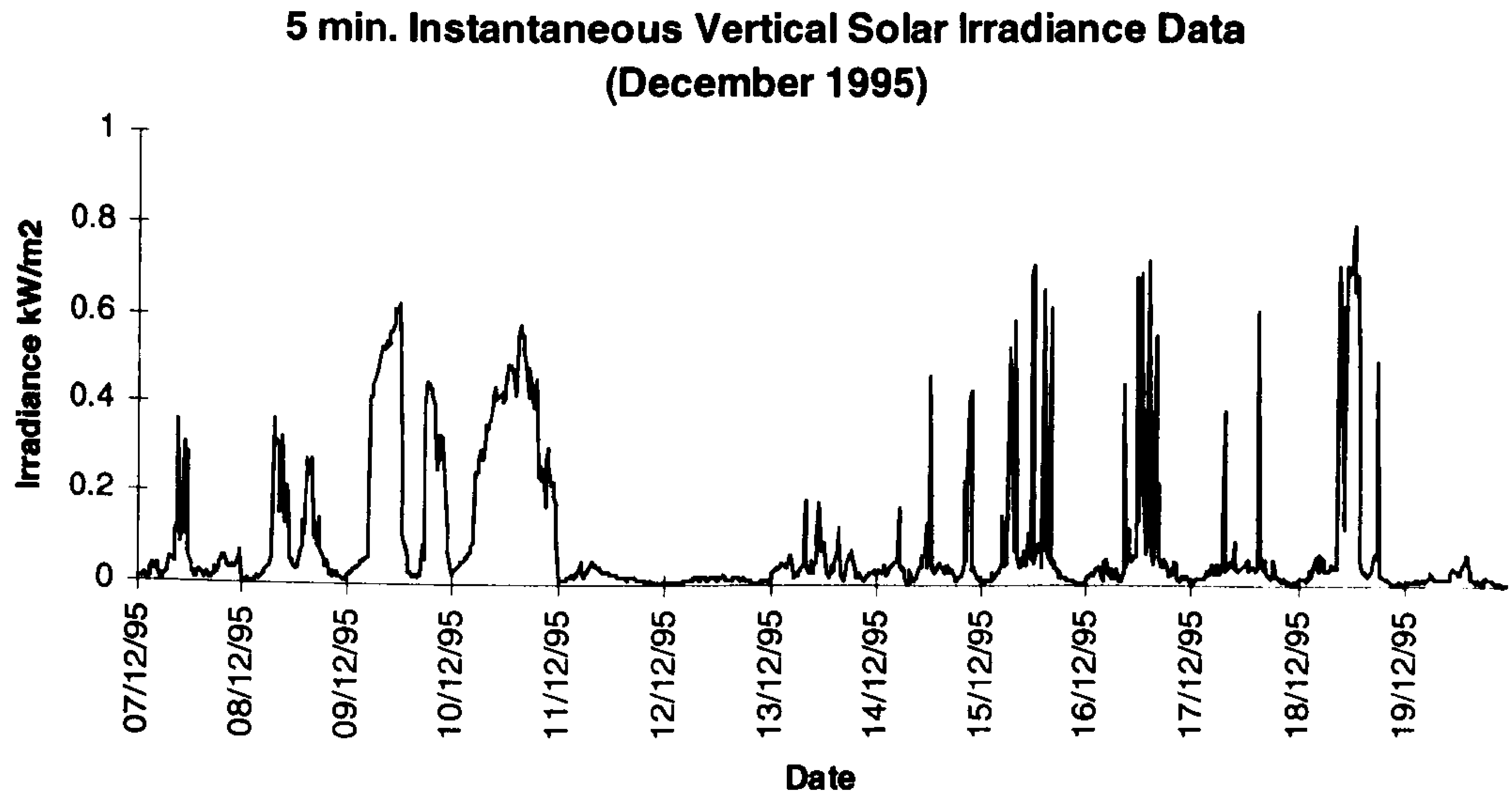
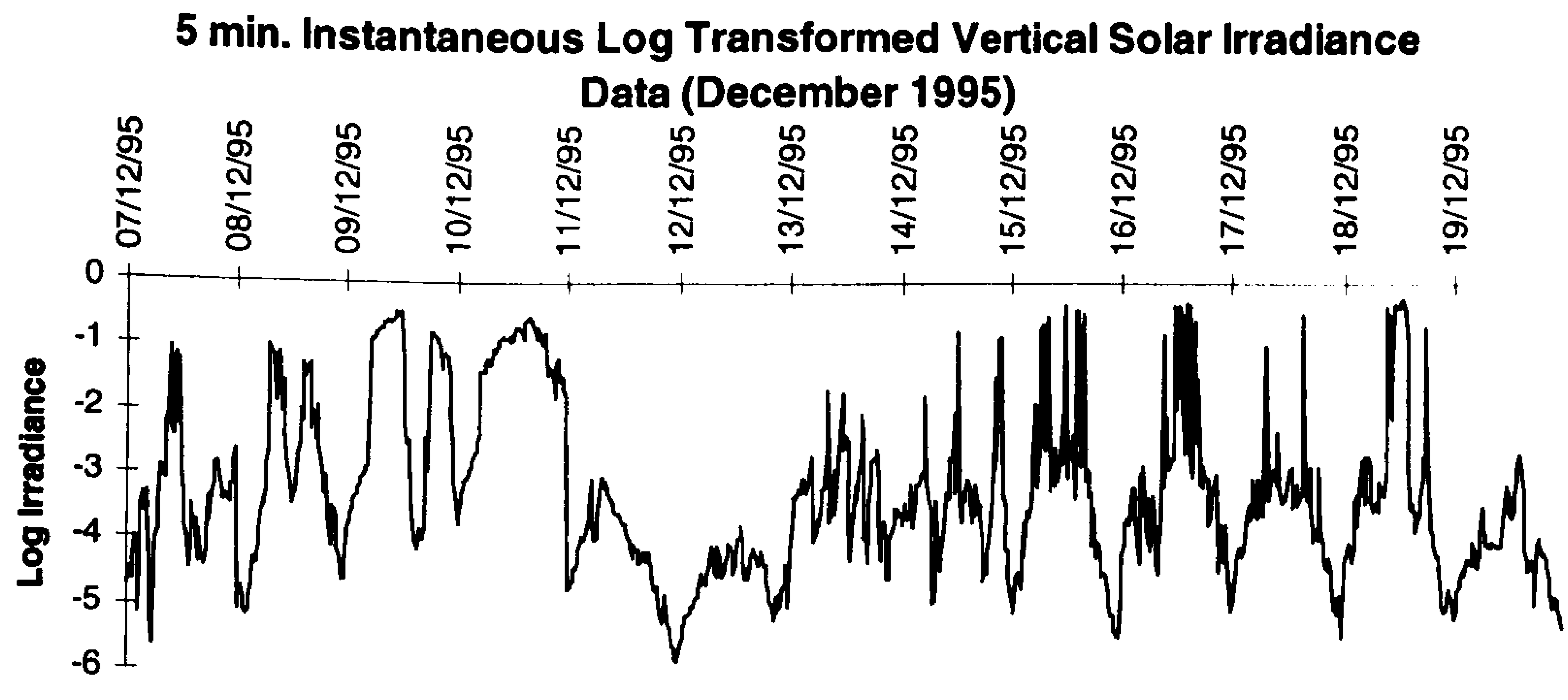


Figure 5.2.4 Log transformed Vertical Solar Irradiance for 5 minute instantaneous data



5.3. Ten minute instantaneous - December 1995

The 10 minute instantaneous Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data are displayed in Figure 5.3.1, Figure 5.3.2, Figure 5.3.3 and Figure 5.3.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.3.1(a), Table 5.3.2(a), Table 5.3.3(a) and Table 5.3.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.3.1(b), Table 5.3.2(b), Table 5.3.3(b) and Table 5.3.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.3.5.

Table 5.3.1 Horizontal Solar Irradiance - 10 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0528	0.0448	0.0125	0.2127
8	0.0603	0.0385	0.0120	0.1544
9	0.0826	0.0474	00197	0.1688
10	0.1038	0.0503	0.0248	0.1699
11	0.0375	0.0206	0.0056	0.0778
12	0.0245	0.0104	0.0072	0.0507
13	0.0565	0.0256	0.0181	0.1201
14	0.0449	0.0194	0.0150	0.0942
15	0.0618	0.0492	0.0081	0.2197
16	0.0614	0.0499	0.0137	0.2199
17	0.0514	0.0316	0.0111	0.1713
18	0.0762	0.0758	0.0137	0.2483
19	0.0365	0.0205	0.0104	0.0968
Overall	0.0577	0.0453	0.0056	0.2843

b)

$2/\sqrt{36} = 0.333$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.744	0.608	0.434	0.168	0.744	0.121	-0.123	-0.355
8	0.810	0.623	0.493	0.286	0.810	-0.098	0.053	-0.316
9	0.811	0.629	0.435	0.219	0.811	-0.082	-0.149	-0.202
10	0.911	0.812	0.704	0.580	0.911	-0.099	-0.113	-0.151
11	0.851	0.706	0.635	0.534	0.851	-0.068	0.187	-0.163
12	0.727	0.514	0.469	0.364	0.727	-0.030	0.226	-0.118
13	0.398	0.126	0.060	0.092	0.398	-0.039	0.028	0.074
14	0.477	0.215	-0.052	-0.059	0.477	-0.015	-0.192	0.055
15	0.262	0.466	0.143	0.266	0.262	0.427	-0.050	0.069
16	0.451	0.363	0.348	0.201	0.451	0.200	0.165	-0.052
17	0.403	0.418	0.291	0.278	0.403	0.306	0.067	0.074
18	0.659	0.407	0.301	0.239	0.659	-0.049	0.092	0.027
19	0.751	0.435	0.313	0.256	0.751	-0.295	0.279	-0.100

Table 5.3.2 Log Transformed Horizontal Solar Irradiance - 10 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.1980	0.6870	-4.3820	-1.5480
8	-3.0430	0.737	-4.4230	-1.8680
9	-2.6890	0.669	-3.9270	-1.7790
10	-2.4098	0.5828	-3.6969	-1.7725
11	-3.4710	0.6780	-5.1850	-2.5540
12	-3.8100	0.4767	-4.9337	-2.9818
13	-2.9723	0.4563	-4.0118	-2.1194
14	-3.1878	0.4205	-4.1997	-2.3623
15	-3.0710	0.7990	-4.8160	-1.5150
16	-3.0180	0.6550	-4.2900	-1.5150
17	-3.1550	0.6560	-4.5010	-1.7640
18	-2.9780	0.8830	-4.2900	-1.2580
19	-3.4560	0.5542	-4.5659	-2.3351
Overall	-3.1121	0.7229	-5.1849	-1.2577

b)

$2/\sqrt{36} = 0.333$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.711	0.526	0.290	0.213	0.711	0.041	-0.199	0.130
8	0.867	0.727	0.596	0.428	0.867	-0.098	-0.046	-0.233
9	0.802	0.596	0.390	0.185	0.802	-0.134	-0.127	-0.146
10	0.867	0.750	0.639	0.521	0.867	-0.009	-0.039	-0.092
11	0.833	0.691	0.590	0.486	0.833	-0.010	0.054	-0.055
12	0.784	0.595	0.470	0.338	0.784	-0.050	0.051	-0.091
13	0.421	0.182	0.109	0.035	0.421	0.006	0.037	-0.030
14	0.497	0.215	-0.080	-0.102	0.497	-0.042	-0.226	0.048
15	0.619	0.583	0.372	0.294	0.619	0.324	-0.131	-0.033
16	0.515	0.491	0.401	0.221	0.515	0.307	0.102	-0.144
17	0.707	0.580	0.425	0.336	0.707	0.161	-0.067	0.020
18	0.704	0.562	0.395	0.293	0.704	0.133	-0.085	0.009
19	0.761	0.532	0.385	0.246	0.761	-0.110	0.045	-0.088

Table 5.3.3 Vertical Solar Irradiance - 10 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0572	0.0846	0.0052	0.3628
8	0.0913	0.1078	0.0058	0.3712
9	0.2576	0.2244	0.0165	0.6277
10	0.3087	0.1706	0.0242	0.5792
11	0.0193	0.0118	0.0032	0.0494
12	0.0114	0.0045	0.0039	0.0232
13	0.0476	0.0361	0.0108	0.1872
14	0.0474	0.0675	0.0078	0.4145
15	0.1078	0.1926	0.0045	0.7128
16	0.1153	0.2027	0.0078	0.7147
17	0.0568	0.1137	0.0063	0.6134
18	0.1630	0.2629	0.0069	0.8043
19	0.0209	0.0152	0.0058	0.0747
Overall	0.1003	0.1666	0.0032	0.8043

b)

$2/\sqrt{36} = 0.333$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.485	0.403	0.336	-0.030	0.485	0.219	0.106	-0.379
8	0.686	0.429	0.242	-0.068	0.686	-0.080	-0.040	-0.376
9	0.806	0.586	0.382	0.174	0.806	-0.183	-0.087	-0.167
10	0.902	0.809	0.706	0.595	0.902	-0.030	-0.103	-0.103
11	0.877	0.718	0.612	0.505	0.877	-0.218	0.164	-0.147
12	0.739	0.531	0.489	0.388	0.739	-0.034	0.240	-0.120
13	0.070	-0.009	-0.154	0.079	0.070	-0.014	-0.153	0.103
14	0.098	-0.021	-0.129	-0.095	0.098	-0.031	-0.125	-0.073
15	-0.034	0.289	-0.103	0.182	-0.034	0.288	-0.094	0.106
16	0.332	0.282	0.301	0.222	0.332	0.193	0.188	0.066
17	-0.020	0.034	-0.044	-0.013	-0.020	0.034	-0.043	-0.016
18	0.658	0.440	0.340	0.159	0.658	0.012	0.080	-0.171
19	0.708	0.335	0.215	0.198	0.708	-0.333	0.305	-0.087

Table 5.3.4 Log Transformed Vertical Solar Irradiance - 10 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.4320	0.9740	-5.2590	-1.0140
8	-3.1190	1.2830	-5.1500	-0.9910
9	-1.9920	1.3020	-4.1040	-0.4660
10	-1.4520	0.9040	-3.7210	-0.5460
11	-4.1500	0.681	-5.7450	-3.0080
12	-4.5560	0.4331	-5.5468	-3.7636
13	-3.2600	0.6440	-4.5280	-1.6760
14	-3.4010	0.7320	-4.8540	-0.8810
15	-3.2540	1.3760	-5.4040	-0.3390
16	-3.0520	1.1930	-4.8540	-0.3360
17	-3.5210	0.9710	-5.0670	-0.4890
18	-2.9880	1.4770	-4.9760	-0.2180
19	-4.0650	0.610	-5.1500	-2.5940
Overall	-3.2493	1.2842	-5.7446	-0.2178

b)

$2/\sqrt{36} = 0.333$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.691	0.488	0.269	0.087	0.691	0.020	-0.144	-0.106
8	0.860	0.679	0.498	0.289	0.860	-0.238	-0.079	-0.245
9	0.839	0.623	0.387	0.135	0.839	-0.276	-0.179	-0.219
10	0.876	0.760	0.649	0.534	0.876	-0.028	-0.047	-0.080
11	0.860	0.733	0.625	0.515	0.860	-0.028	0.001	-0.066
12	0.794	0.599	0.480	0.349	0.794	-0.086	0.085	-0.113
13	0.269	0.006	-0.143	-0.026	0.269	-0.071	-0.136	0.056
14	0.490	0.170	-0.210	-0.342	0.490	-0.093	-0.339	-0.128
15	0.551	0.603	0.312	0.291	0.551	0.429	-0.201	0.037
16	0.555	0.507	0.468	0.314	0.555	0.287	0.170	-0.088
17	0.437	0.448	0.242	0.247	0.437	0.318	-0.041	0.058
18	0.747	0.577	0.393	0.219	0.747	0.044	-0.117	-0.116
19	0.733	0.471	0.338	0.219	0.733	-0.144	0.107	-0.085

Table 5.3.5 Summary information from fitted ARIMA models

(a)

	10 minute instantaneous Horizontal Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(1,1,0)	53	(1,0,0)	54
8	(1,0,0)	70		
9	(1,0,0)	71	(1,0,0)	75
10	(1,1,0)	95	(1,1,0)	95
11	(1,0,0)	80		
12	(1,0,0)	58	(1,0,0)	74
13	(1,0,0)	16	(1,0,0)	20
14	(1,0,0)	22	(1,0,0)	24
15	(1,1,0)	18	(1,1,0)	61
16	(1,0,0)	19	(1,1,0)	40
17	(1,0,0)	16	(1,1,0)	69
18	(1,0,0)	42	(1,1,0)	52
19	(2,1,0)	68	(1,0,0)	71

(b)

	10 minute instantaneous Vertical Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(1,1,0)	14	(1,0,0)	51
8	(1,0,0)	47	(1,1,0)	83
9	(1,0,0)	68	(1,1,0)	77
10			(1,1,0)	94
11	(1,0,0)	83		
12	(2,1,0)	61	(1,0,0)	75
13	(4,1,0)		(1,1,0)	
14	(3,1,0)		(1,0,0)	22
15	(1,0,0)		(1,1,0)	51
16	(2,1,0)		(1,1,0)	36
17	(1,1,0)		(1,1,0)	30
18	(1,0,0)	42	(1,0,0)	58
19	(2,1,0)	60	(1,0,0)	66

Figure 5.3.1 Horizontal Solar Irradiance for 10 minute instantaneous data

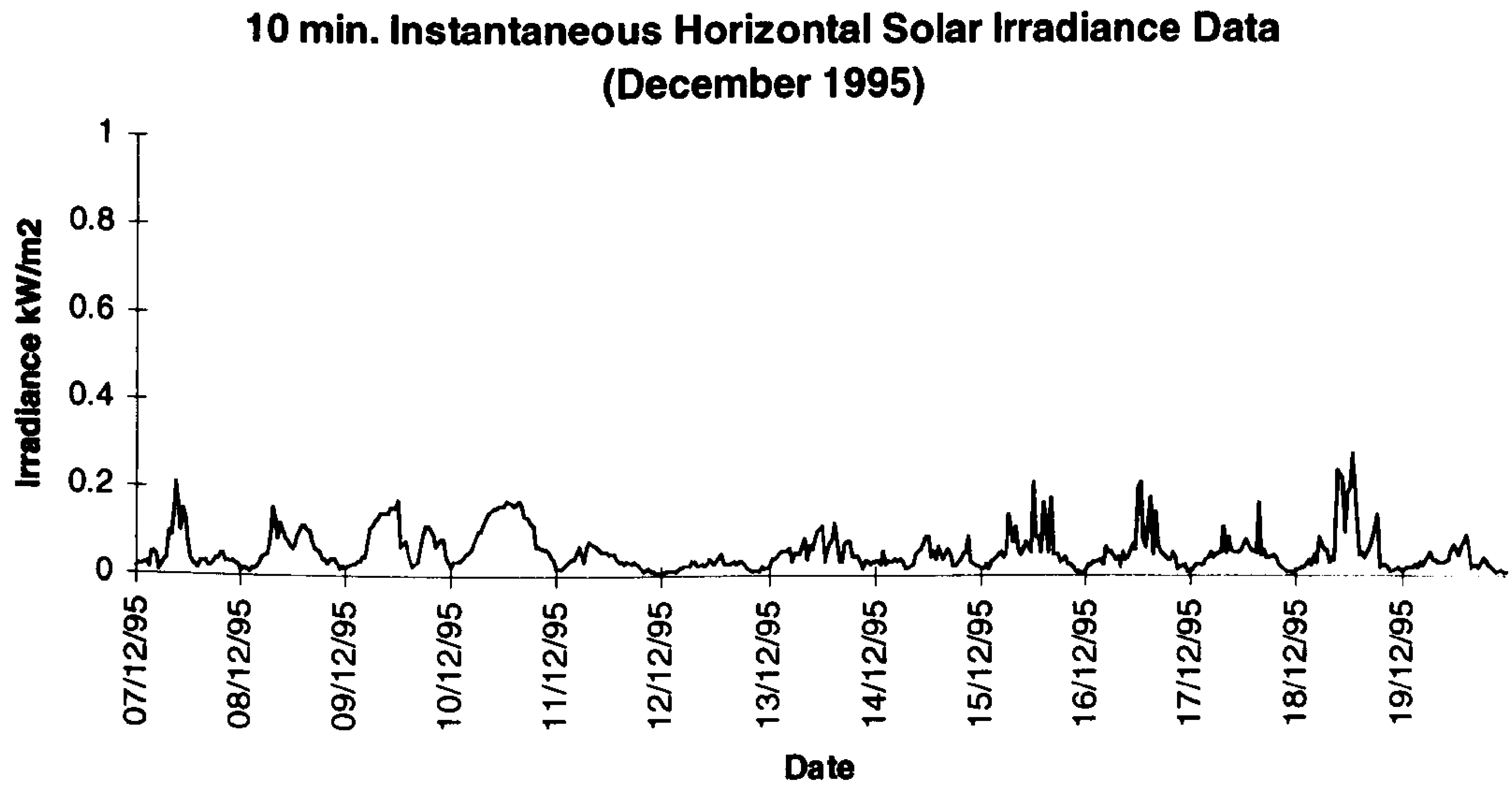


Figure 5.3.2 Log transformed Horizontal Solar Irradiance for 10 minute instantaneous data

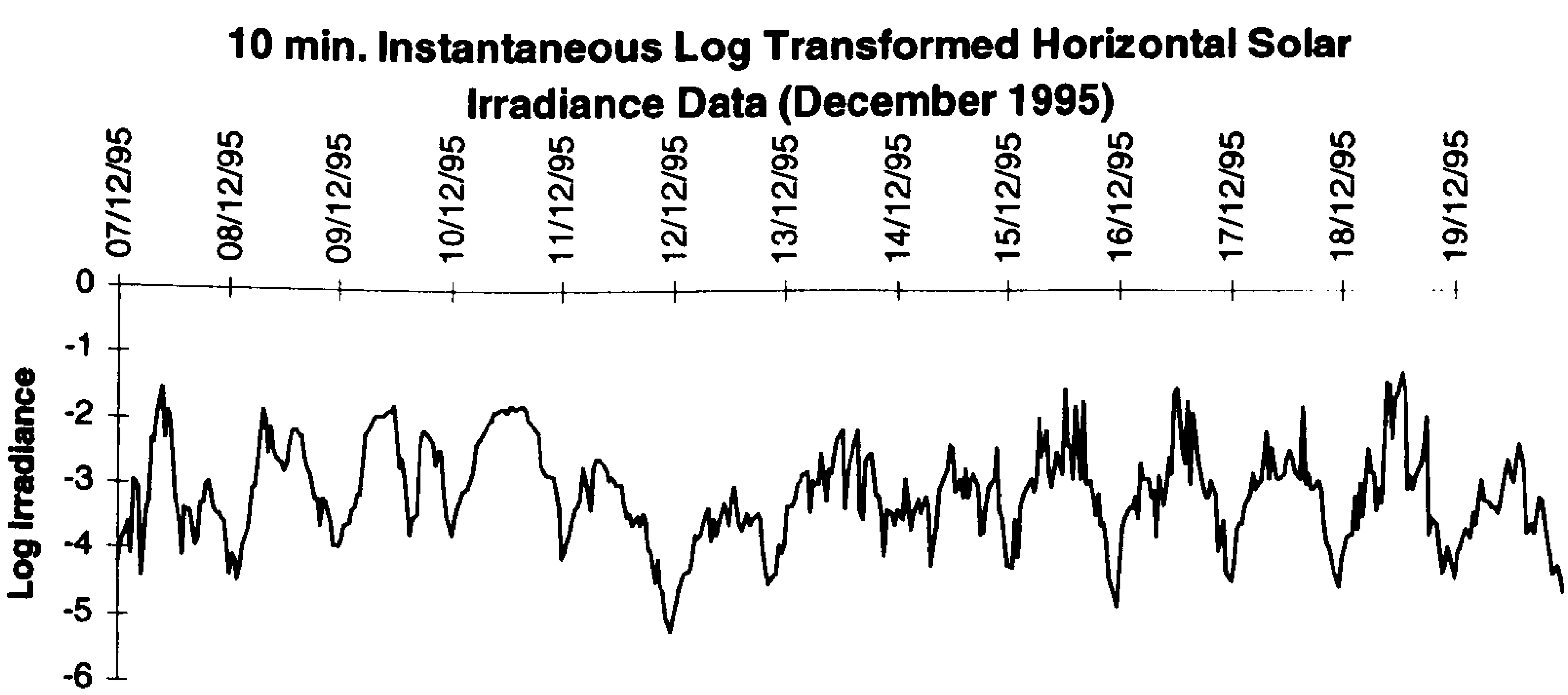


Figure 5.3.3 Vertical Solar Irradiance for 10 minute instantaneous data

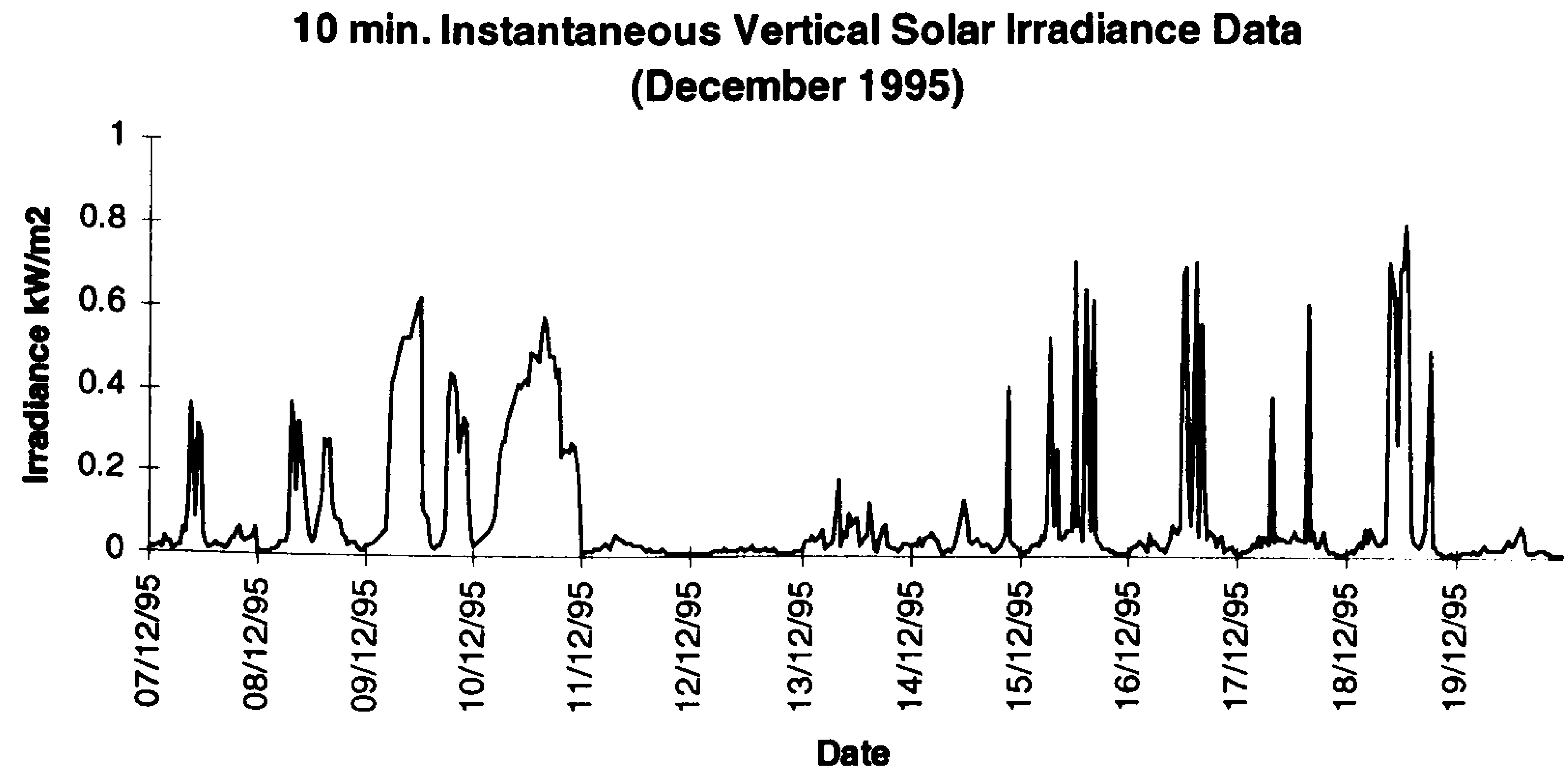
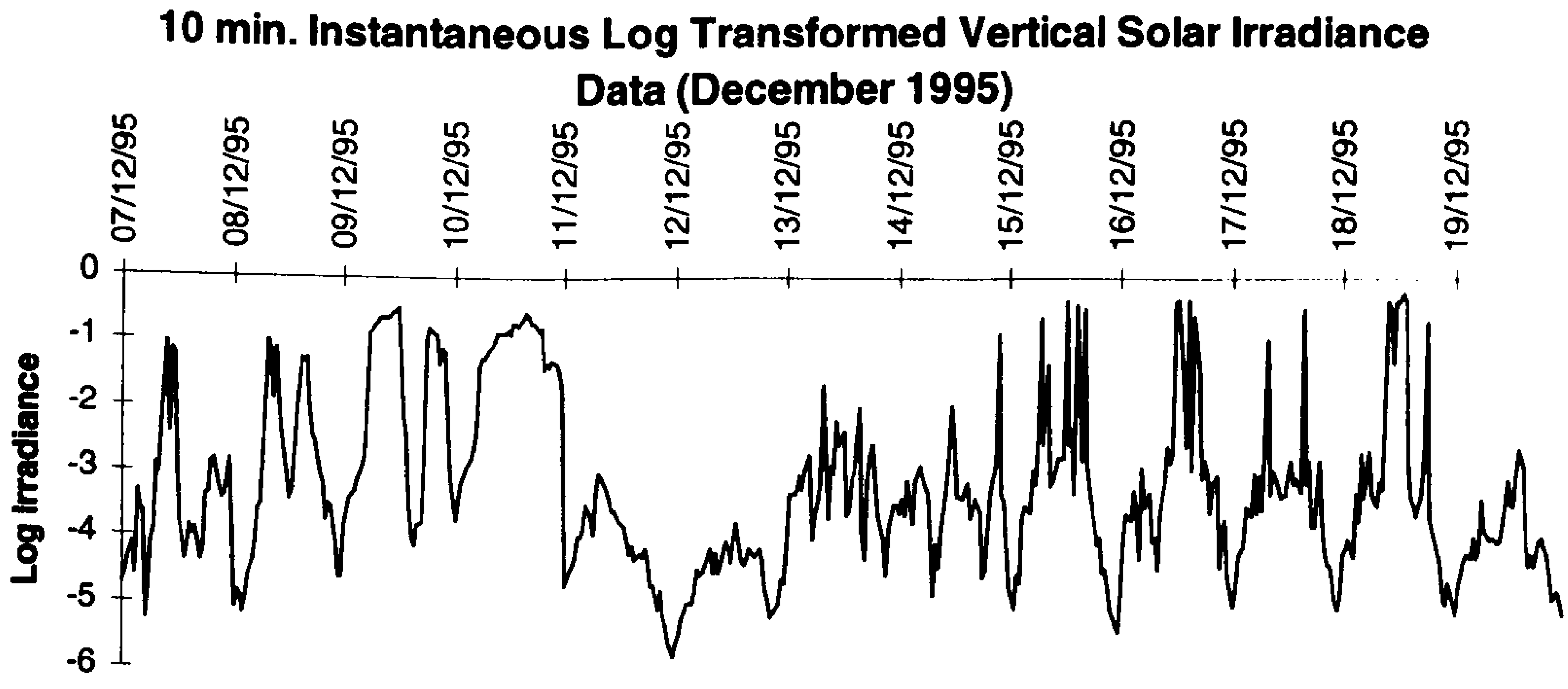


Figure 5.3.4 Log transformed Vertical Solar Irradiance for 10 minute instantaneous data



5.4. Five minute averages - December 1995

The 5 minute averaged Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data are displayed in Figure 5.4.1, Figure 5.4.2, Figure 5.4.3 and Figure 5.4.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.4.1(a), Table 5.4.2(a), Table 5.4.3(a) and Table 5.4.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.4.1(b), Table 5.4.2(b), Table 5.4.3(b) and Table 5.4.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.4.5.

Table 5.4.1 Horizontal Solar Irradiance - 5 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0493	0.0366	0.0087	0.01709
8	0.0592	0.0355	0.0118	0.1460
9	0.0828	0.0460	0.0203	0.1619
10	0.1031	0.0496	0.0262	0.1699
11	0.0376	0.0211	0.0048	0.0864
12	0.0246	0.0097	0.0074	0.0498
13	0.0561	0.0241	0.0145	0.1168
14	0.0466	0.0197	0.0144	0.1047
15	0.0626	0.0422	0.0075	0.2036
16	0.0636	0.0415	0.0121	0.1798
17	0.0486	0.0223	0.0073	0.0931
18	0.0728	0.0701	0.0135	0.2837
19	0.0365	0.0203	0.0092	0.0958
Overall	0.0572	0.0411	0.0051	0.2623

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.903	0.807	0.715	0.636	0.903	-0.044	-0.028	0.013
8	0.930	0.844	0.767	0.675	0.930	-0.148	0.029	-0.173
9	0.936	0.840	0.741	0.644	0.936	-0.289	-0.026	-0.031
10	0.956	0.907	0.857	0.806	0.956	-0.082	-0.028	-0.043
11	0.930	0.833	0.747	0.691	0.930	-0.243	0.078	0.142
12	0.867	0.689	0.546	0.488	0.867	-0.249	0.072	0.212
13	0.784	0.501	0.253	0.119	0.784	-0.295	-0.068	0.094
14	0.745	0.497	0.334	0.208	0.745	-0.130	0.028	-0.045
15	0.694	0.626	0.577	0.630	0.694	0.278	0.146	0.286
16	0.790	0.660	0.619	0.564	0.790	0.094	0.194	0.024
17	0.831	0.758	0.695	0.669	0.831	0.216	0.071	0.133
18	0.903	0.766	0.654	0.573	0.903	-0.274	0.118	0.037
19	0.918	0.772	0.619	0.499	0.918	-0.443	0.022	0.142

Table 5.4.2 Log Transformed Horizontal Solar Irradiance - 5 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.2336	0.6574	-4.7398	-1.7666
8	-3.0386	0.6964	-1.4397	-1.9239
9	-2.6779	0.6492	-3.8971	-1.8207
10	-2.4167	0.5766	-3.6428	-1.7727
11	-3.4849	0.7143	-5.3308	-2.4483
12	-3.7953	0.4445	-4.9009	-3.0001
13	-2.9707	0.4316	-4.2309	-2.1469
14	-3.1502	0.4122	-4.2378	-2.2565
15	-3.0368	0.7957	-4.8875	-1.5913
16	-2.9479	0.6312	-4.4145	-1.7156
17	-3.1695	0.5985	-4.9254	-2.3745
18	-2.9925	0.8414	-4.3065	-1.2598
19	-3.4571	0.5542	-4.6907	-2.3455
Overall	-3.1144	0.6949	-5.2746	-1.3423

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.863	0.694	0.558	0.453	0.863	-0.201	0.050	0.003
8	0.939	0.875	0.814	0.740	0.939	-0.062	-0.003	-0.148
9	0.919	0.810	0.699	0.591	0.919	-0.229	-0.037	-0.049
10	0.926	0.858	0.796	0.738	0.926	0.004	0.010	-0.005
11	0.927	0.844	0.768	0.703	0.927	-0.108	0.011	0.030
12	0.867	0.732	0.620	0.553	0.867	-0.079	0.018	0.108
13	0.756	0.492	0.302	0.213	0.756	-0.187	0.002	0.082
14	0.726	0.451	0.323	0.215	0.726	-0.162	0.131	-0.081
15	0.856	0.777	0.709	0.651	0.856	0.166	0.048	0.027
16	0.786	0.659	0.574	0.534	0.786	0.108	0.073	0.110
17	0.854	0.757	0.698	0.635	0.854	0.103	0.112	-0.000
18	0.908	0.801	0.720	0.653	0.908	-0.136	0.096	0.012
19	0.904	0.788	0.673	0.580	0.904	-0.165	-0.043	0.051

Table 5.4.3 Vertical Solar Irradiance - 5 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0447	0.0456	0.0038	0.2141
8	0.0856	0.0953	0.0060	0.3461
9	0.2601	0.2184	0.0166	0.6239
10	0.3049	0.1639	0.0258	0.5734
11	0.0193	0.0118	0.0030	0.0480
12	0.0115	0.0042	0.0039	0.0222
13	0.0456	0.0291	0.0095	0.1655
14	0.0589	0.0739	0.0067	0.3978
15	0.1071	0.1383	0.0043	0.6133
16	0.1178	0.1555	0.0102	0.6238
17	0.0395	0.0352	0.0042	0.1714
18	0.1511	0.2433	0.0067	0.8118
19	0.0206	0.0149	0.0051	0.0742
Overall	0.0975	0.1471	0.0032	0.7790

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.761	0.683	0.633	0.491	0.761	0.247	0.136	-0.179
8	0.864	0.718	0.627	0.477	0.864	-0.115	0.138	-0.321
9	0.941	0.837	0.724	0.603	0.941	-0.420	0.002	-0.129
10	0.949	0.892	0.840	0.790	0.949	-0.077	0.011	-0.012
11	0.940	0.848	0.767	0.706	0.940	-0.313	0.144	0.049
12	0.870	0.691	0.553	0.493	0.870	-0.269	0.110	0.180
13	0.634	0.256	0.044	0.037	0.634	-0.245	-0.004	-0.013
14	0.604	0.343	0.132	0.057	0.604	-0.034	-0.097	0.040
15	0.513	0.346	0.337	0.463	0.513	0.114	0.167	0.307
16	0.717	0.526	0.482	0.495	0.717	0.024	0.200	0.166
17	0.457	0.332	0.206	0.219	0.457	0.156	0.008	0.111
18	0.909	0.785	0.690	0.621	0.909	-0.233	0.135	0.030
19	0.913	0.736	0.543	0.388	0.913	-0.581	0.092	0.160

Table 5.4.4 Log Transformed Vertical Solar Irradiance - 5 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.4890	0.8620	-5.5730	-1.5410
8	-3.1110	1.2110	-5.1190	-1.0610
9	-1.9530	1.2690	-4.1000	-0.4720
10	-1.4440	0.8540	-3.6590	-0.5560
11	-4.1608	0.7054	-5.7959	-3.0361
12	-4.5418	0.4021	-5.5366	-3.8077
13	-3.2608	0.5893	-4.6544	-1.7989
14	-3.2750	0.8560	-4.9970	-0.9220
15	-3.1230	1.4250	-5.4490	-0.4890
16	-2.8820	1.1900	-4.5870	-0.4720
17	-3.5485	0.8183	-5.4679	-1.7636
18	-3.0060	1.4350	-5.0000	-0.2090
19	-4.0765	0.6063	-5.2746	-2.6007
Overall	-3.2530	1.2283	-5.7615	-0.2518

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.859	0.703	0.577	0.464	0.859	-0.137	0.032	-0.044
8	0.935	0.859	0.784	0.688	0.935	-0.127	-0.015	0.220
9	0.935	0.843	0.736	0.613	0.935	-0.253	-0.136	-0.159
10	0.933	0.866	0.805	0.745	0.933	-0.029	0.002	-0.018
11	0.939	0.866	0.800	0.741	0.939	-0.132	0.039	-0.001
12	0.873	0.733	0.622	0.555	0.873	-0.124	0.044	0.107
13	0.729	0.361	0.123	0.017	0.729	-0.362	0.068	-0.005
14	0.753	0.526	0.330	0.164	0.753	-0.094	-0.075	-0.074
15	0.840	0.751	0.706	0.682	0.840	0.152	0.149	0.125
16	0.797	0.641	0.540	0.528	0.797	0.016	0.068	0.206
17	0.746	0.650	0.586	0.529	0.746	0.211	0.110	0.049
18	0.915	0.819	0.730	0.655	0.915	-0.115	-0.001	0.026
19	0.902	0.762	0.628	0.520	0.902	-0.271	-0.005	0.047

Table 5.4.5 Summary information from fitted ARIMA models

(a)

	5 Minute Averaged Horizontal Solar Irradiance Data			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(1,0,0)	82	(1,0,0)	76
8	(1,0,0)	90	(1,1,0)	94
9	(1,1,0)	93	(1,1,0)	94
10	(1,1,0)	98	(1,1,0)	98
11	(2,1,0)	92	(1,1,0)	96
12	(3,1,0)	85	(1,1,0)	87
13	(3,1,0)	65	(1,0,0)	63
14	(1,0,0)	57	(1,0,0)	56
15	(3,1,0)	60	(1,1,0)	83
16	(2,1,0)	65	(1,1,0)	70
17	(1,1,0)	77	(1,1,0)	88
18	(1,1,0)	83	(1,1,0)	85
19	(3,1,0)	93	(1,1,0)	93

(b)

	5 Minute Averaged Vertical Solar Irradiance Data			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(1,1,0)	58	(1,0,0)	77
8	(3,1,0)	77	(3,1,0)	93
9	(2,1,0)	94	(1,1,0)	93
10	(1,1,0)	96	(1,1,0)	97
11	(2,1,0)	94	(2,1,0)	97
12	(2,1,0)	85	(1,1,0)	88
13	(2,0,0)	43	(2,1,0)	55
14	(1,0,0)	36	(1,0,0)	58
15	(3,1,0)	32	(4,1,0)	78
16	(3,1,0)	52	(3,1,0)	67
17	(3,1,0)	14	(1,1,0)	65
18	(1,1,0)	83		
19	(2,1,0)	93	(2,1,0)	93

Figure 5.4.1 Horizontal Solar Irradiance for 5 minute averaged data

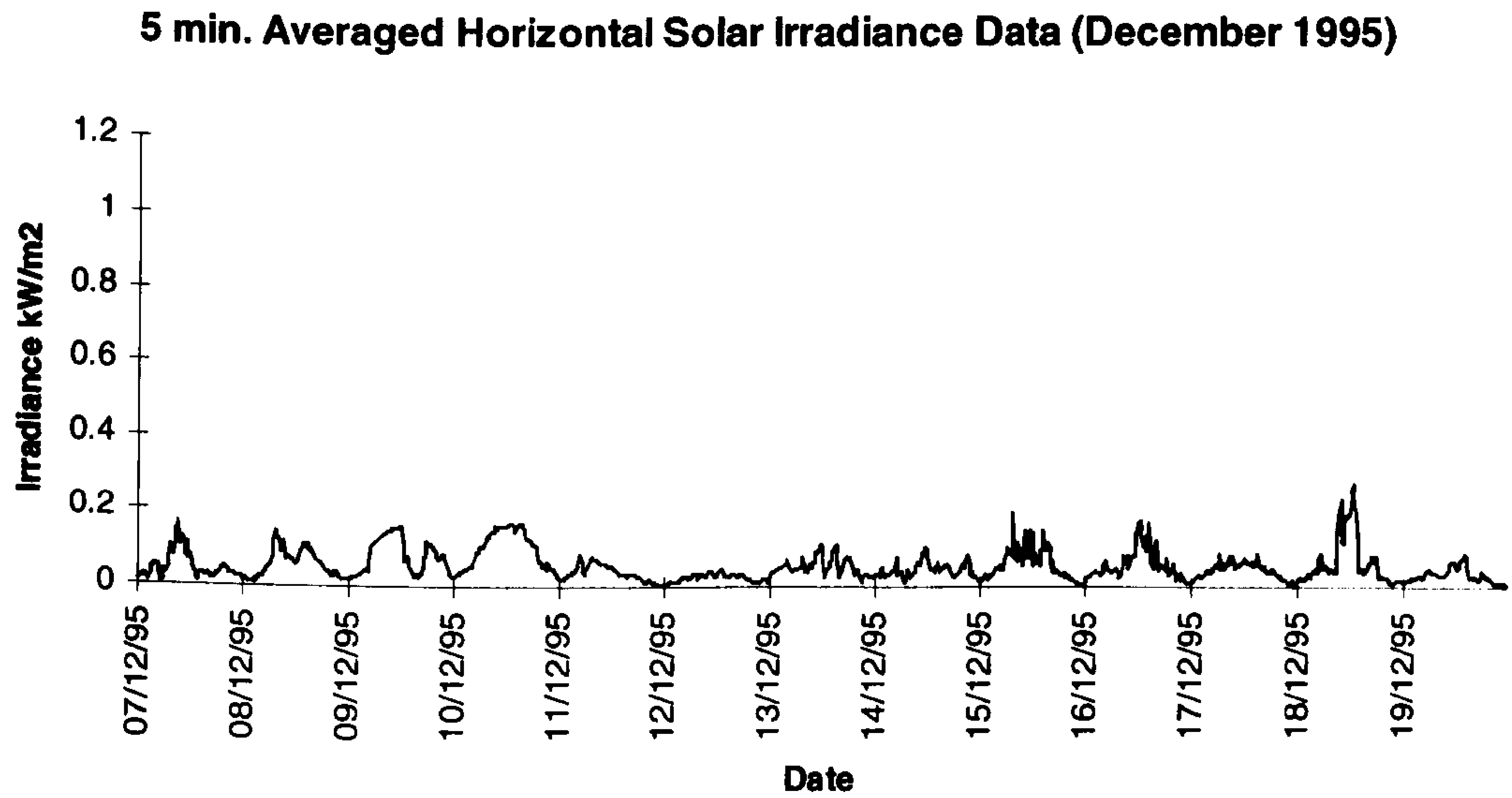


Figure 5.4.2 Log transformed Horizontal Solar Irradiance for 5 minute averaged data

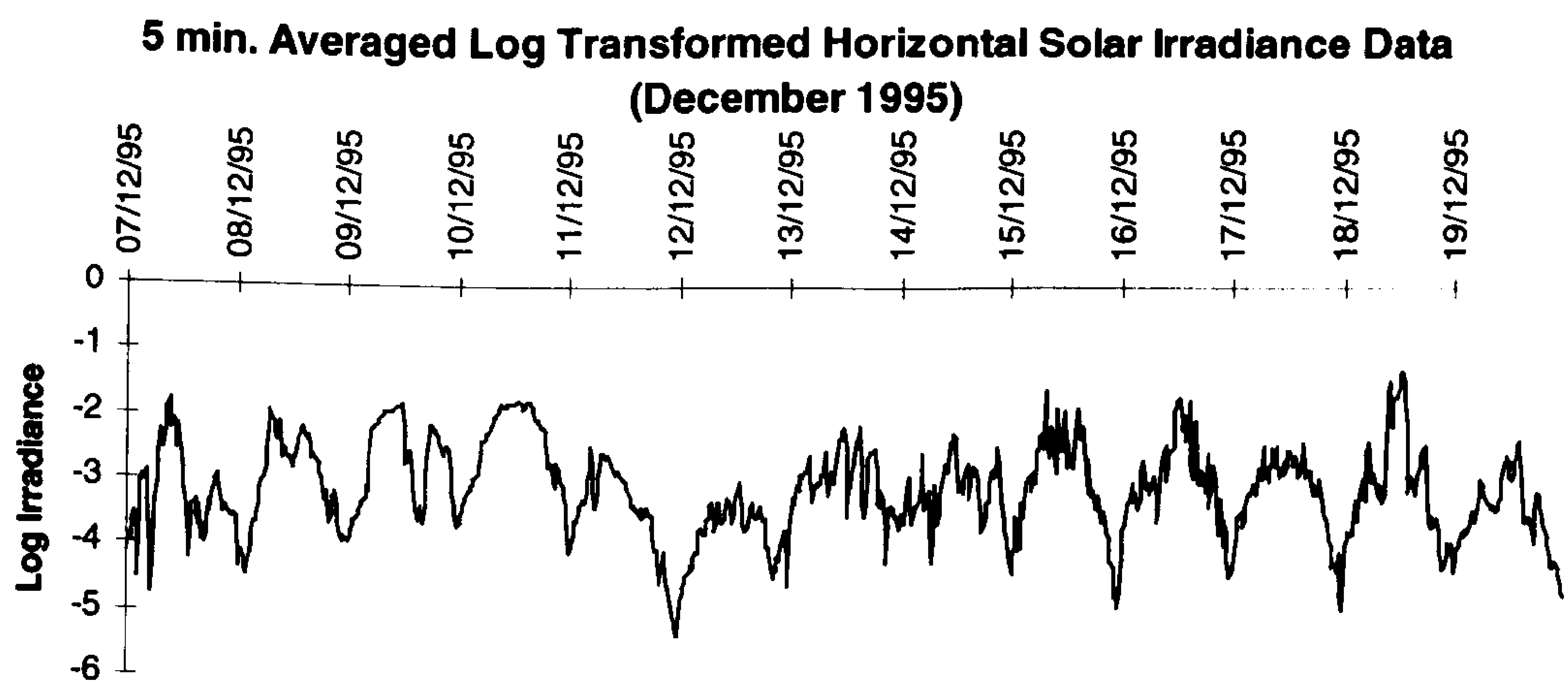


Figure 5.4.3 Vertical Solar Irradiance for 5 minute averaged data

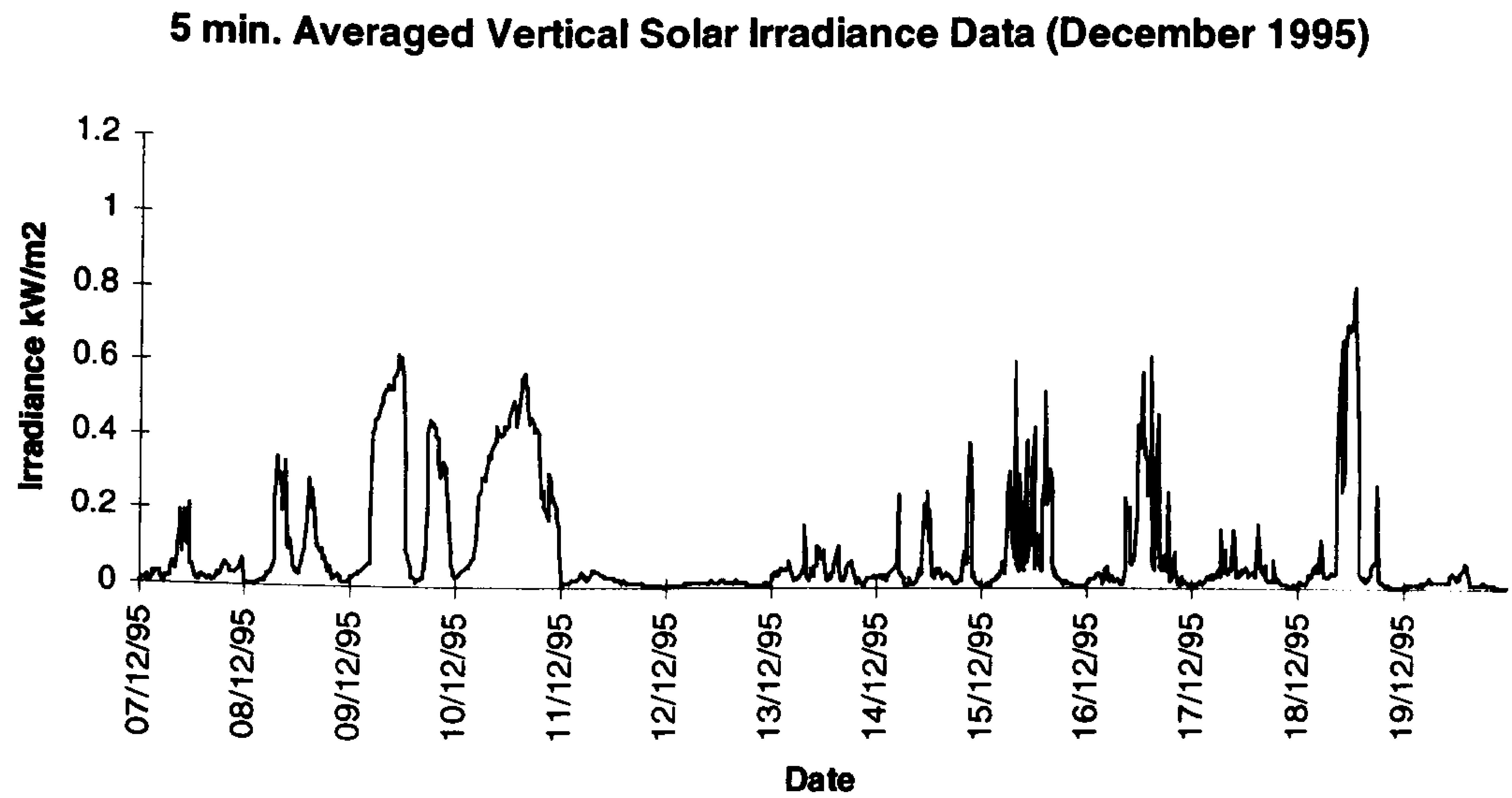
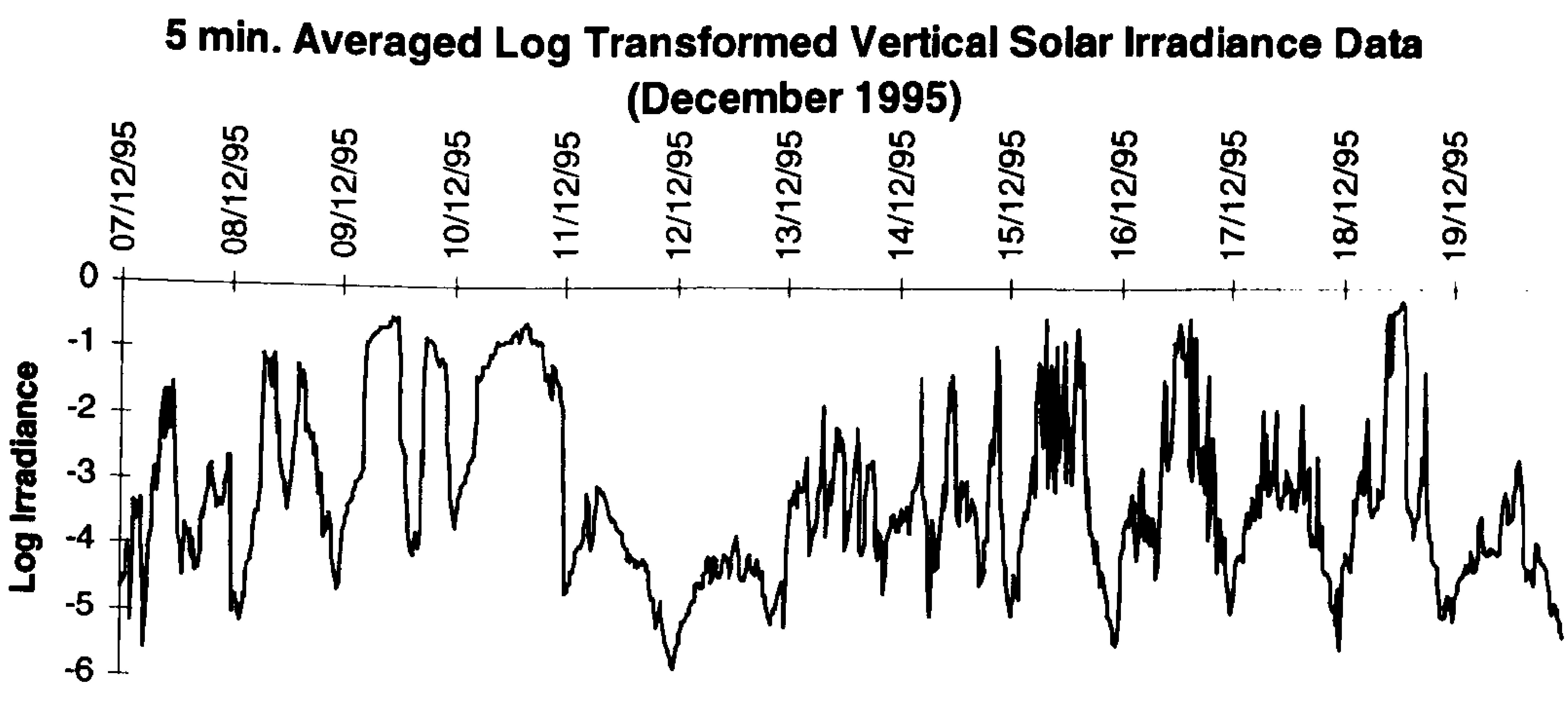


Figure 5.4.4 Log transformed Vertical Solar Irradiance for 5 minute averaged data



5.5. Ten minute averages - December 1995

The 10 minute averaged Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data are displayed in Figure 5.5.1, Figure 5.5.2, Figure 5.5.3 and Figure 5.5.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.5.1(a), Table 5.5.2(a), Table 5.5.3(a) and Table 5.5.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.5.1(b), Table 5.5.2(b), Table 5.5.3(b) and Table 5.5.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.5.5.

Table 5.5.1 Horizontal Solar Irradiance - 10 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0493	0.0358	0.0108	0.1509
8	0.0592	0.0351	0.0138	0.1378
9	0.0828	0.0459	0.0211	0.1582
10	0.1031	0.0498	0.0278	0.1690
11	0.0376	0.0210	0.0051	0.0762
12	0.0246	0.0095	0.0078	0.0463
13	0.0561	0.0231	0.0203	0.1127
14	0.0466	0.0187	0.0201	0.0966
15	0.0626	0.0384	0.0083	0.1452
16	0.0636	0.0395	0.0122	0.1702
17	0.0486	0.0217	0.0081	0.0817
18	0.0728	0.0691	0.0137	0.2623
19	0.0365	0.0201	0.0096	0.0904
Overall	0.0572	0.0421	0.0048	0.2837

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.854	0.659	0.433	0.232	0.854	-0.256	-0.218	-0.028
8	0.881	0.700	0.513	0.324	0.881	-0.344	-0.067	-0.139
9	0.855	0.653	0.447	0.228	0.855	-0.288	-0.103	-0.197
10	0.909	0.808	0.695	0.581	0.909	-0.105	-0.121	-0.070
11	0.847	0.710	0.649	0.563	0.847	-0.026	0.192	-0.109
12	0.741	0.532	0.510	0.412	0.741	-0.037	0.287	-0.147
13	0.577	0.143	-0.010	0.145	0.577	-0.285	0.079	0.257
14	0.568	0.227	-0.045	-0.089	0.568	-0.140	-0.169	0.066
15	0.812	0.669	0.496	0.425	0.812	0.027	-0.159	0.174
16	0.762	0.641	0.464	0.407	0.762	0.146	-0.150	0.127
17	0.814	0.712	0.584	0.482	0.814	0.144	-0.087	-0.023
18	0.797	0.601	0.412	0.276	0.797	-0.093	-0.104	0.016
19	0.793	0.530	0.396	0.317	0.793	-0.267	0.218	-0.091

Table 5.5.2 Log Transformed Horizontal Solar Irradiance - 10 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.2220	0.6410	-4.5280	-1.8910
8	-3.0350	0.6970	-4.2780	-1.9820
9	-2.6750	0.6480	-3.8590	-1.8440
10	-2.4157	0.5784	-3.5816	-1.7778
11	-3.4830	0.7160	-5.2730	-2.5750
12	-3.7912	0.4382	-4.8536	-3.0733
13	-2.9629	0.4138	-3.8957	-2.1825
14	-3.1422	0.3943	-3.9065	-2.3373
15	-3.0180	0.7860	-4.7850	-1.9300
16	-2.9320	0.6110	-4.4030	-1.7710
17	-3.1643	0.5940	-4.8097	-2.5049
18	-2.9760	0.8310	-4.2870	-1.3380
19	-3.4529	0.5509	-4.6491	-2.4035
Overall	-3.1144	0.7052	-5.3308	-1.2598

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.750	0.472	0.274	0.154	0.750	-0.205	0.002	0.007
8	0.890	0.750	0.588	0.419	0.890	-0.197	-0.177	-0.116
9	0.822	0.597	0.384	0.165	0.822	-0.245	-0.084	-0.186
10	0.860	0.740	0.620	0.520	0.860	0.003	-0.063	0.004
11	0.852	0.710	0.603	0.513	0.852	-0.059	0.047	-0.003
12	0.767	0.583	0.491	0.369	0.767	-0.014	0.118	-0.106
13	0.560	0.240	0.083	0.145	0.560	-0.107	-0.008	0.181
14	0.517	0.223	-0.093	-0.113	0.517	-0.061	-0.251	0.071
15	0.835	0.670	0.526	0.410	0.835	-0.090	-0.028	-0.003
16	0.727	0.589	0.448	0.384	0.727	0.127	-0.040	0.079
17	0.778	0.654	0.529	0.388	0.778	0.122	-0.033	-0.113
18	0.849	0.674	0.509	0.355	0.849	-0.168	-0.065	-0.070
19	0.810	0.603	0.463	0.328	0.810	-0.156	0.072	-0.104

Table 5.5.3 Vertical Solar Irradiance - 10 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	0.0447	0.0417	0.0053	0.1535
8	0.0856	0.0915	0.0068	0.3198
9	0.2601	0.2174	0.0171	0.6133
10	0.3049	0.1644	0.0279	0.5650
11	0.0193	0.0118	0.0031	0.0448
12	0.0115	0.0041	0.0040	0.0208
13	0.0456	0.0263	0.0123	0.1122
14	0.0589	0.0688	0.0099	0.3293
15	0.1071	0.1143	0.0046	0.3790
16	0.1178	0.1440	0.0104	0.5232
17	0.0395	0.0294	0.0050	0.1148
18	0.1511	0.2414	0.0069	0.7790
19	0.0206	0.0147	0.0054	0.0716
Overall	0.0975	0.1510	0.0030	0.8118

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.834	0.607	0.317	0.071	0.834	-0.292	-0.336	-0.010
8	0.820	0.519	0.228	-0.042	0.820	-0.464	-0.058	-0.225
9	0.853	0.617	0.386	0.167	0.853	-0.407	-0.032	-0.160
10	0.898	0.795	0.682	0.587	0.898	-0.064	-0.106	0.029
11	0.860	0.723	0.650	0.545	0.860	-0.062	0.166	-0.172
12	0.746	0.537	0.515	0.427	0.746	-0.042	0.292	-0.130
13	0.399	-0.059	-0.246	0.027	0.399	-0.259	-0.144	0.245
14	0.400	0.041	-0.244	-0.212	0.400	-0.141	-0.251	-0.010
15	0.688	0.471	0.230	0.228	0.688	-0.004	-0.177	0.266
16	0.665	0.602	0.441	0.380	0.665	0.287	-0.069	0.031
17	0.527	0.266	0.295	0.265	0.527	-0.016	0.223	0.036
18	0.802	0.638	0.426	0.193	0.802	-0.015	-0.230	-0.230
19	0.760	0.422	0.268	0.218	0.760	-0.370	0.303	-0.099

Table 5.5.4 Log Transformed Vertical Solar Irradiance - 10 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
7	-3.4650	0.8470	-5.2480	-1.8740
8	-3.0950	1.2180	-4.9910	-1.1400
9	-1.9360	1.260	-4.0690	-0.4890
10	-1.4410	0.8560	-3.5810	-0.5710
11	-4.1590	0.7080	-5.7600	-3.1050
12	-4.5384	0.3963	-5.1150	-3.8733
13	-3.2412	0.5659	-4.3990	-2.1873
14	-3.2470	0.8470	-4.6160	-1.1110
15	-3.0380	1.4390	-5.3820	-0.9700
16	-2.8170	1.1700	-4.5690	-0.6480
17	-3.5150	0.8090	-5.2900	-2.1640
18	-2.9690	1.4360	-4.9810	-0.2500
19	-4.0720	0.6070	-5.2250	-2.6370
Overall	-3.2530	1.2452	-5.7962	-0.2086

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
7	0.765	0.495	0.248	0.073	0.765	-0.219	-0.118	-0.021
8	0.879	0.702	0.497	0.285	0.879	-0.307	-0.191	-0.139
9	0.850	0.621	0.367	0.105	0.850	-0.369	-0.179	-0.198
10	0.869	0.747	0.622	0.510	0.869	-0.032	-0.083	-0.026
11	0.873	0.747	0.644	0.547	0.873	-0.063	0.026	-0.037
12	0.773	0.586	0.497	0.378	0.773	-0.027	0.132	-0.109
13	0.447	0.004	-0.195	0.010	0.447	-0.245	-0.116	0.224
14	0.562	0.161	-0.315	-0.385	0.562	-0.227	-0.459	0.085
15	0.858	0.709	0.551	0.429	0.858	-0.102	-0.124	0.041
16	0.714	0.602	0.501	0.461	0.714	0.189	0.038	0.100
17	0.713	0.537	0.467	0.337	0.713	0.059	0.133	-0.107
18	0.840	0.658	0.463	0.258	0.840	-0.164	-0.152	-0.162
19	0.777	0.539	0.388	0.252	0.777	-0.164	0.071	-0.092

Table 5.5.5 Summary information from fitted ARIMA models

(a)

	10 Minute Averaged Horizontal Solar Irradiance Data			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(1,0,0)	75	(1,0,0)	58
8	(1,1,0)	86	(1,1,0)	90
9	(1,1,0)	82	(1,1,0)	83
10	(4,1,0)	96	(1,1,0)	94
11	(2,1,0)	80		
12	(2,1,0)	69	(2,1,0)	76
13	(3,1,0)	40	(3,1,0)	32
14	(1,0,0)	33	(1,0,0)	29
15	(1,0,0)	73	(1,1,0)	89
16	(1,0,0)	63	(1,0,0)	69
17	(1,0,0)	79		
18	(1,0,0)	65	(1,0,0)	78
19	(2,1,0)	72	(2,1,0)	83

(b)

	10 Minute Averaged Vertical Solar Irradiance Data			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
7	(1,0,0)	71	(1,0,0)	63
8	(1,1,0)	71	(1,1,0)	87
9	(1,1,0)	80	(1,1,0)	84
10	(1,1,0)	91	(1,1,0)	93
11	(1,0,0)	79		
12	(2,1,0)	70	(2,1,0)	76
13	(4,1,0)	32	(4,1,0)	30
14	(1,0,0)	14	(3,1,0)	28
15	(3,1,0)	49		
16	(1,1,0)	46	(1,1,0)	57
17	(2,1,0)	27	(2,1,0)	66
18	(1,0,0)	65	(1,0,0)	75
19	(2,1,0)	69	(1,0,0)	72

Figure 5.5.1 Horizontal Solar Irradiance for 10 minute averaged data

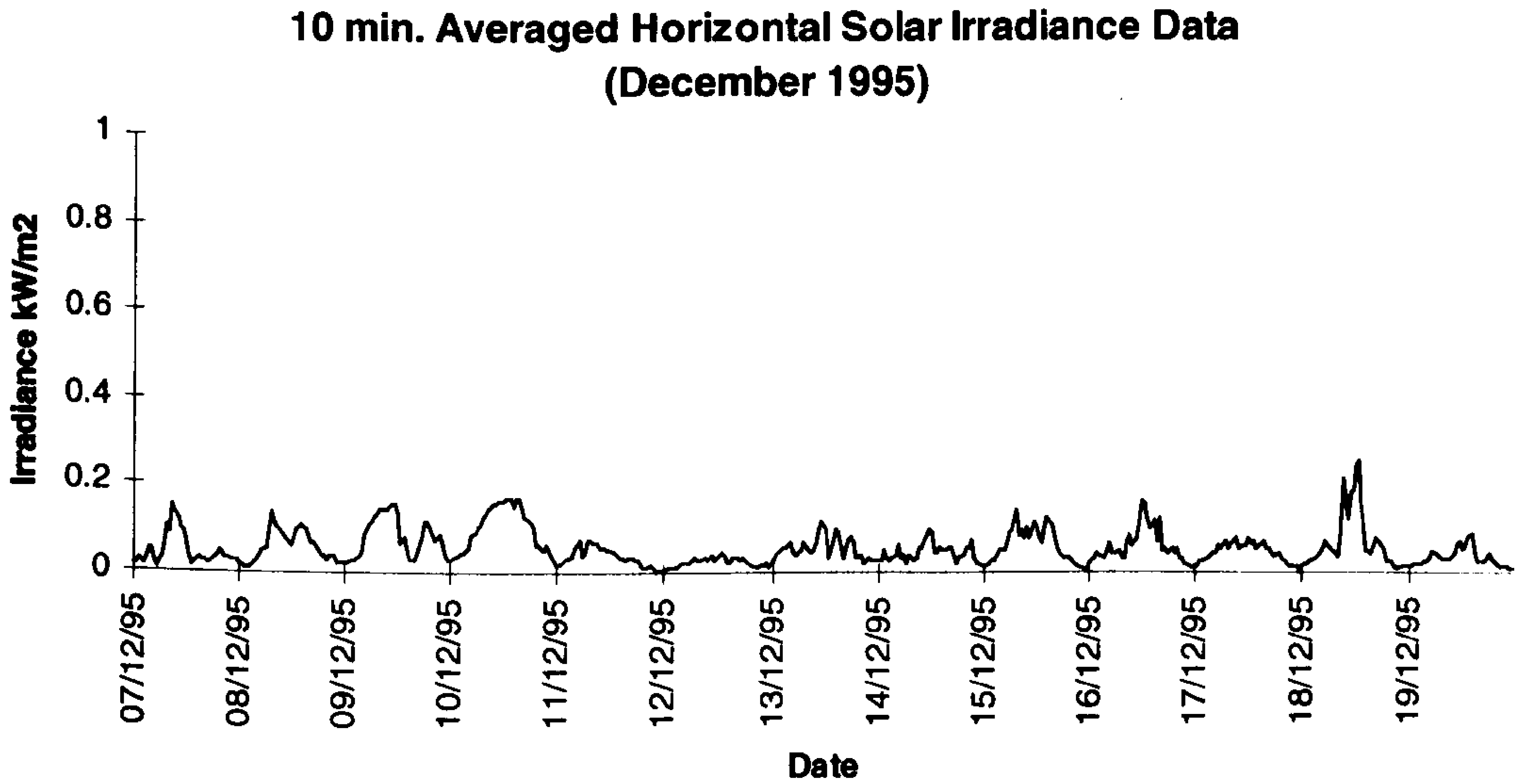


Figure 5.5.2 Log transformed Horizontal Solar Irradiance for 10 minute averaged data

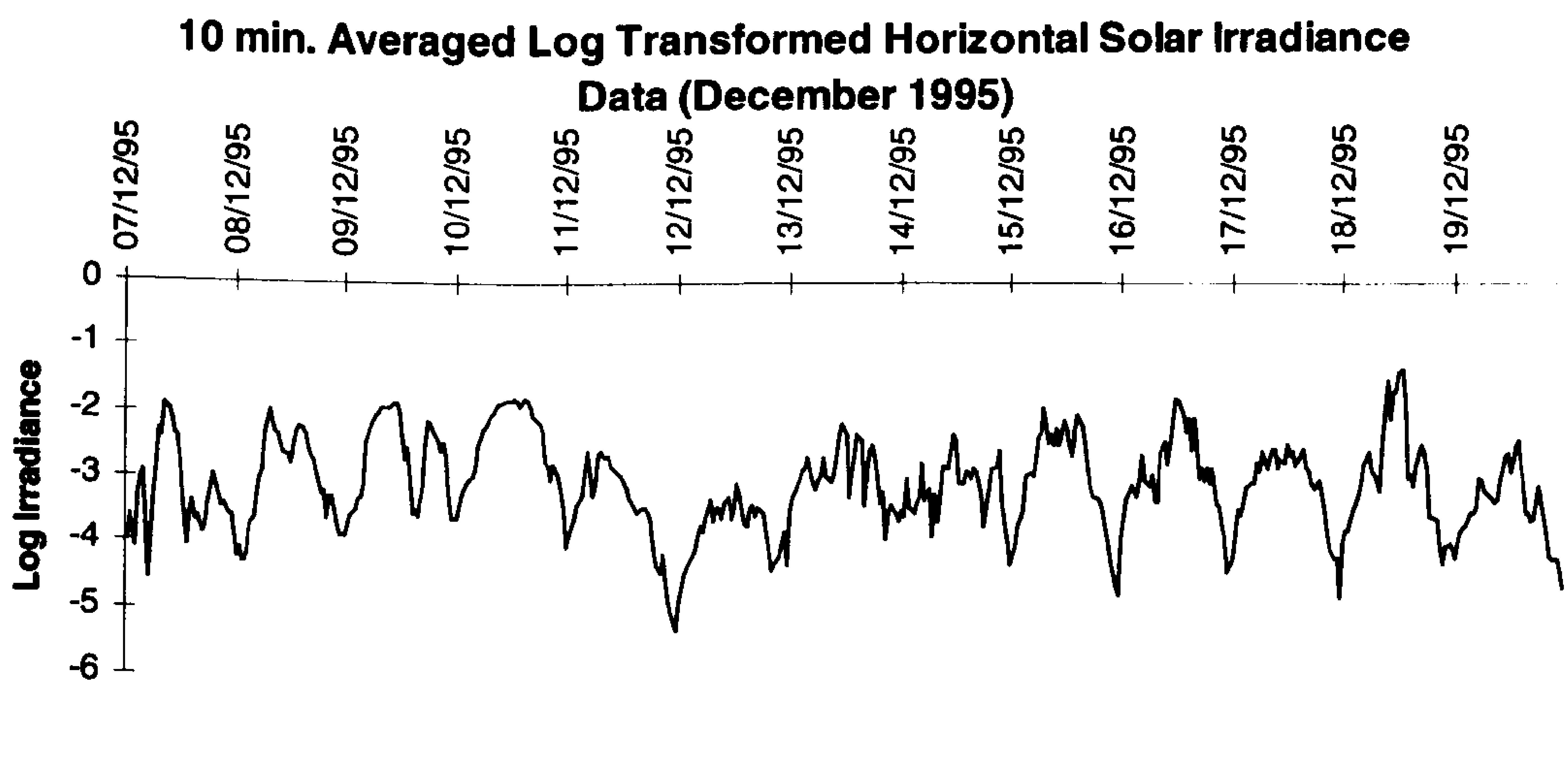


Figure 5.5.3 Vertical Solar Irradiance for 10 minute averaged data

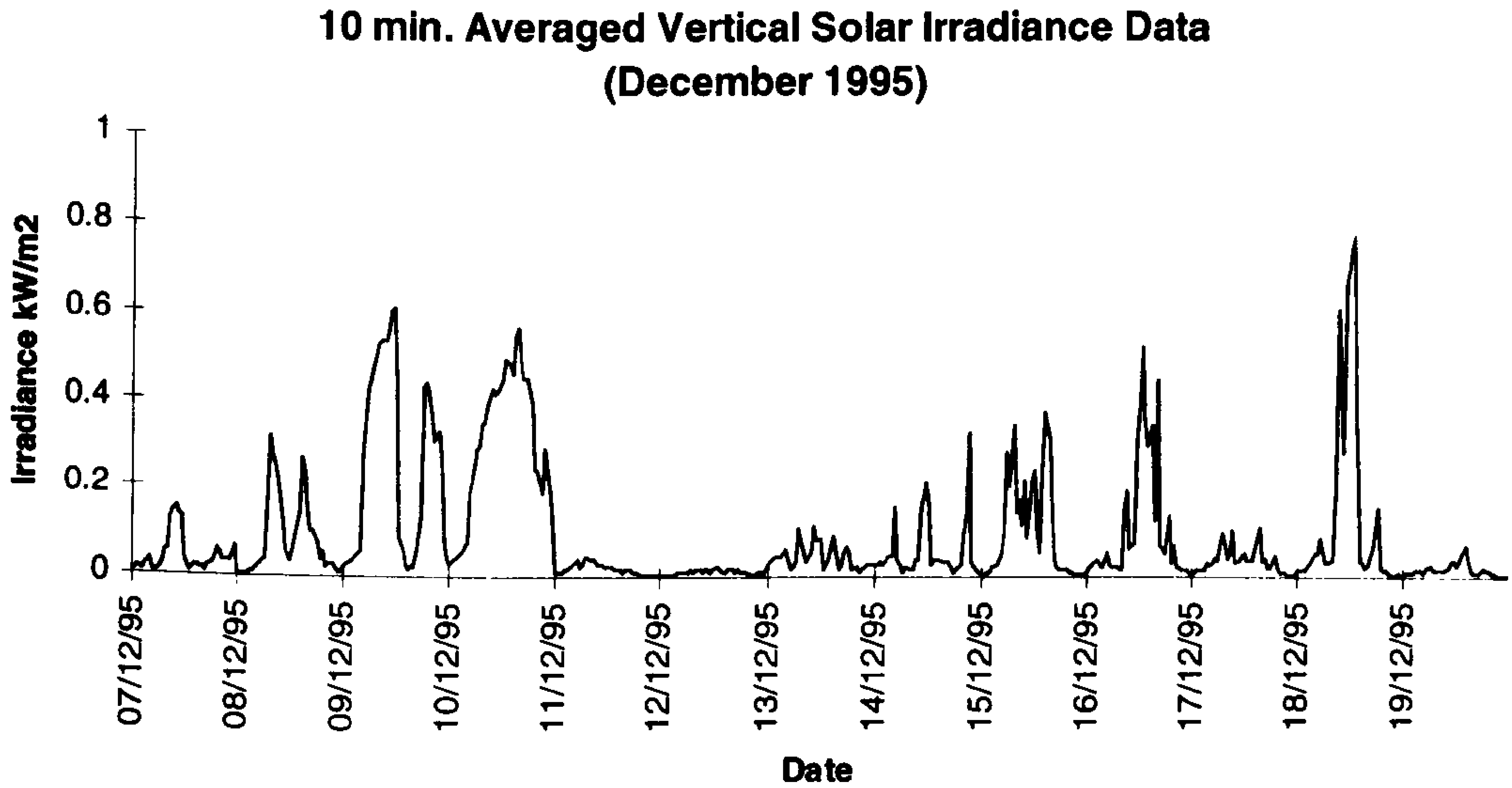
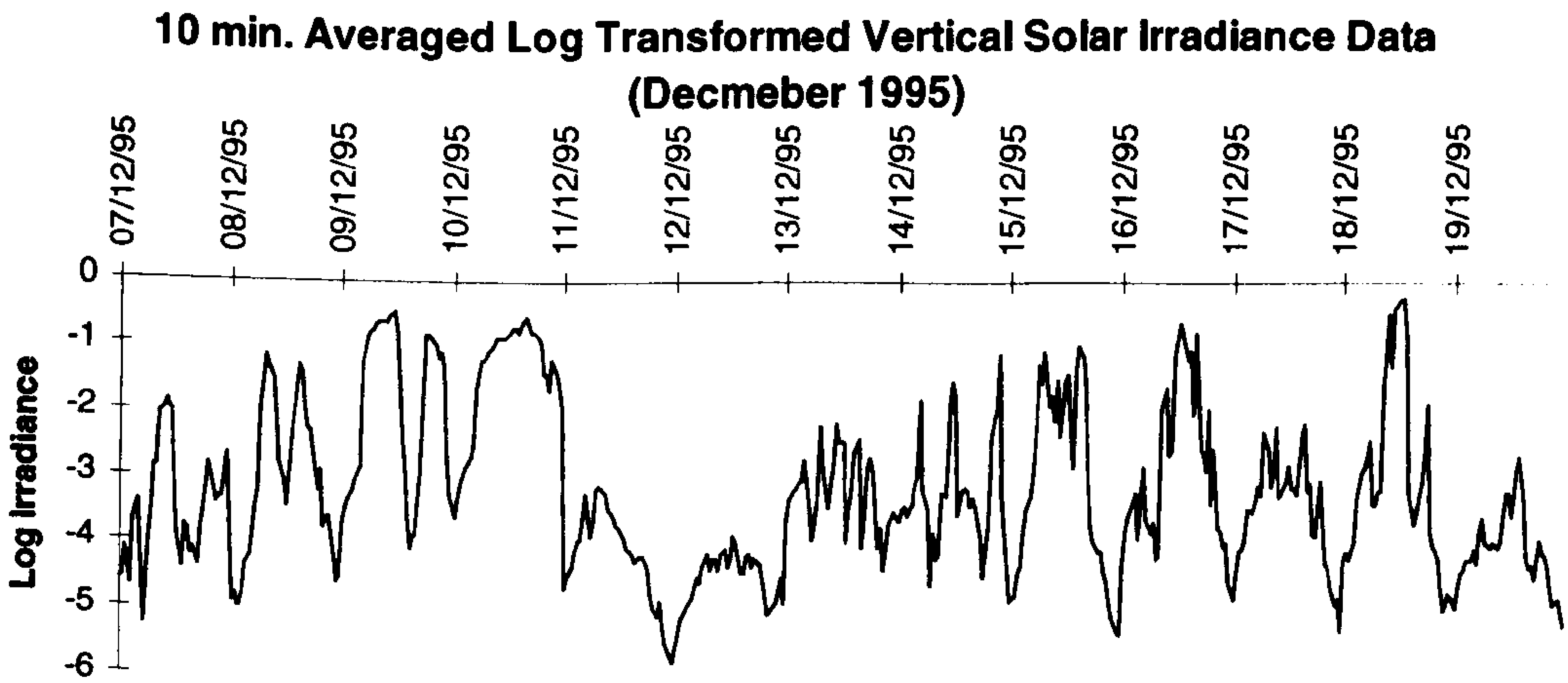


Figure 5.5.4 Log transformed Vertical Solar Irradiance for 10 minute averaged data



5.6. One minute instantaneous data values - July 1994

The 1 minute instantaneous Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data for the three types of day, Good, Average and Overcast, are displayed in Figure 5.6.1, Figure 5.6.2, Figure 5.6.3 and Figure 5.6.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.6.6(a), Table 5.6.7(a), Table 5.6.8(a) and Table 5.6.9(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.6.6(b), Table 5.6.7(b), Table 5.6.8(b) and Table 5.6.9(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.6.10. NB Excel will only plot 4000 datapoints on a graph and so the graphs for the average type days only contain 4000 points.

Table 5.6.6 Horizontal Solar Irradiance - 1 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.1975	0.1691	0.0053	1.0930
10	0.1318	0.1057	0.0037	0.6569
11	0.1690	0.1613	0.0030	0.7977
12	0.2786	0.2098	0.0032	0.9599
13	0.3253	0.2490	0.0025	1.2480
14	0.3927	0.3197	0.0042	1.0000
15	0.3240	0.3106	0.0023	1.1650
16	0.3275	0.2480	0.0030	1.2350
17	0.4261	0.3086	0.0032	1.1000
18	0.2268	0.1531	0.0035	0.8512
19	0.3879	0.2868	0.0021	1.0570
Overall	0.2898	0.2571	0.0021	1.2480

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.962	0.930	0.887	0.855	0.962	0.054	-0.160	0.119
10	0.970	0.931	0.901	0.871	0.970	-0.149	0.142	-0.073
11	0.956	0.935	0.921	0.909	0.956	0.245	0.151	0.087
12	0.950	0.911	0.889	0.877	0.950	0.092	0.168	0.138
13	0.838	0.773	0.743	0.744	0.838	0.235	0.179	0.205
14	0.974	0.959	0.946	0.936	0.974	0.202	0.083	0.080
15	0.945	0.926	0.913	0.892	0.945	0.308	0.172	-0.005
16	0.929	0.877	0.842	0.807	0.929	0.105	0.110	0.021
17	0.936	0.880	0.849	0.833	0.936	0.035	0.175	0.132
18	0.965	0.953	0.935	0.929	0.965	0.307	0.020	0.166
19	0.901	0.848	0.821	0.810	0.901	0.190	0.168	0.165

Table 5.6.7 Log Transformed Horizontal Solar Irradiance - 1 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.0364	1.0297	-5.2400	0.0889
10	-2.3302	0.8551	-5.9940	-0.4202
11	-2.3262	1.1856	-5.8091	-0.2260
12	-1.7325	1.1821	-5.7446	-0.0513
13	-1.5828	1.2260	-5.9915	0.2215
14	-1.5891	1.4219	-5.4727	0.0000
15	-1.8115	1.3871	-6.0748	0.1527
16	-1.5764	1.1907	-5.8091	0.2111
17	-1.3078	1.1979	-5.7446	0.0953
18	-1.8883	1.1385	-5.6550	-0.1611
19	-1.4760	1.3248	-6.1658	0.0554
Overall	-1.7870	1.2448	-6.1658	0.2215

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.988	0.974	0.959	0.944	0.988	-0.066	-0.074	-0.004
10	0.981	0.956	0.930	0.905	0.981	-0.188	-0.001	0.004
11	0.989	0.978	0.969	0.959	0.989	0.043	0.021	-0.018
12	0.981	0.962	0.945	0.930	0.981	-0.011	0.040	0.068
13	0.971	0.952	0.937	0.927	0.971	0.159	0.093	0.120
14	0.988	0.979	0.970	0.962	0.988	0.088	0.026	0.030
15	0.985	0.973	0.962	0.949	0.985	0.110	0.030	-0.044
16	0.975	0.974	0.953	0.916	0.975	0.048	0.064	0.010
17	0.973	0.947	0.927	0.912	0.973	0.021	0.089	0.089
18	0.989	0.979	0.968	0.958	0.989	0.056	-0.024	0.017
19	0.972	0.952	0.937	0.924	0.972	0.144	0.101	0.059

Table 5.6.8 Vertical Solar Irradiance - 1 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.0989	0.1034	0.0026	0.7335
10	0.0551	0.0371	0.0022	0.1985
11	0.0877	0.0970	0.0019	0.5515
12	0.1417	0.1253	0.0015	0.6407
13	0.1848	0.1935	0.0015	0.8593
14	0.2488	0.2289	0.0024	0.7236
15	0.2090	0.2284	0.0013	0.8019
16	0.1772	0.1722	0.0019	0.8392
17	0.2356	0.2151	0.0015	0.7740
18	0.1167	0.0980	0.0024	0.5725
19	0.2465	0.2285	0.0011	0.7636
Overall	0.1638	0.1817	0.0011	0.8593

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.956	0.918	0.869	0.835	0.956	0.056	-0.152	0.142
10	0.985	0.961	0.941	0.923	0.985	-0.300	0.223	-0.083
11	0.954	0.935	0.921	0.911	0.954	0.281	0.140	0.107
12	0.944	0.907	0.888	0.876	0.944	0.145	0.185	0.117
13	0.861	0.805	0.780	0.781	0.861	0.247	0.187	0.208
14	0.977	0.963	0.953	0.943	0.977	0.188	0.106	0.060
15	0.950	0.934	0.924	0.905	0.950	0.324	0.183	0.004
16	0.941	0.898	0.869	0.840	0.941	0.105	0.127	0.018
17	0.940	0.890	0.861	0.845	0.940	0.052	0.171	0.116
18	0.968	0.958	0.941	0.938	0.968	0.332	0.006	0.190
19	0.934	0.896	0.881	0.875	0.934	0.190	0.210	0.169

Table 5.6.9 Log Transformed Vertical Solar Irradiance - 1 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.8145	1.1026	-5.9522	-0.3099
10	-3.1614	0.8013	-6.1193	-1.6170
11	-3.0573	1.2152	-6.2659	-0.5951
12	-2.4829	1.2371	-6.5023	-0.4452
13	-2.3445	1.3400	-6.5023	-0.1516
14	-2.1751	1.5369	-6.0323	-0.3235
15	-2.5326	1.5002	-6.6454	-0.2208
16	-2.3056	1.2373	-6.2659	-0.1753
17	-2.0542	1.3125	-6.5023	-0.2562
18	-2.6288	1.1730	-6.0323	-0.5577
19	-2.1141	1.4571	-6.8124	-0.2697
Overall	-2.5031	1.3275	-6.8125	-0.1516

b)

$2/\sqrt{990} = 0.064$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.989	0.977	0.964	0.950	0.989	-0.051	-0.072	-0.001
10	0.985	0.965	0.944	0.923	0.985	-0.157	-0.012	-0.008
11	0.990	0.982	0.974	0.965	0.990	0.038	0.023	-0.038
12	0.983	0.966	0.951	0.938	0.983	0.007	0.039	0.048
13	0.978	0.964	0.953	0.946	0.978	0.164	0.108	0.123
14	0.990	0.983	0.975	0.968	0.990	0.077	0.028	0.019
15	0.987	0.978	0.970	0.960	0.987	0.137	0.032	-0.033
16	0.982	0.966	0.953	0.939	0.982	0.051	0.066	-0.005
17	0.982	0.965	0.951	0.940	0.982	0.015	0.101	0.069
18	0.991	0.984	0.975	0.967	0.991	0.058	-0.035	0.019
19	0.982	0.968	0.958	0.949	0.982	0.123	0.111	0.047

Table 5.6.10 Summary information from fitted ARIMA models

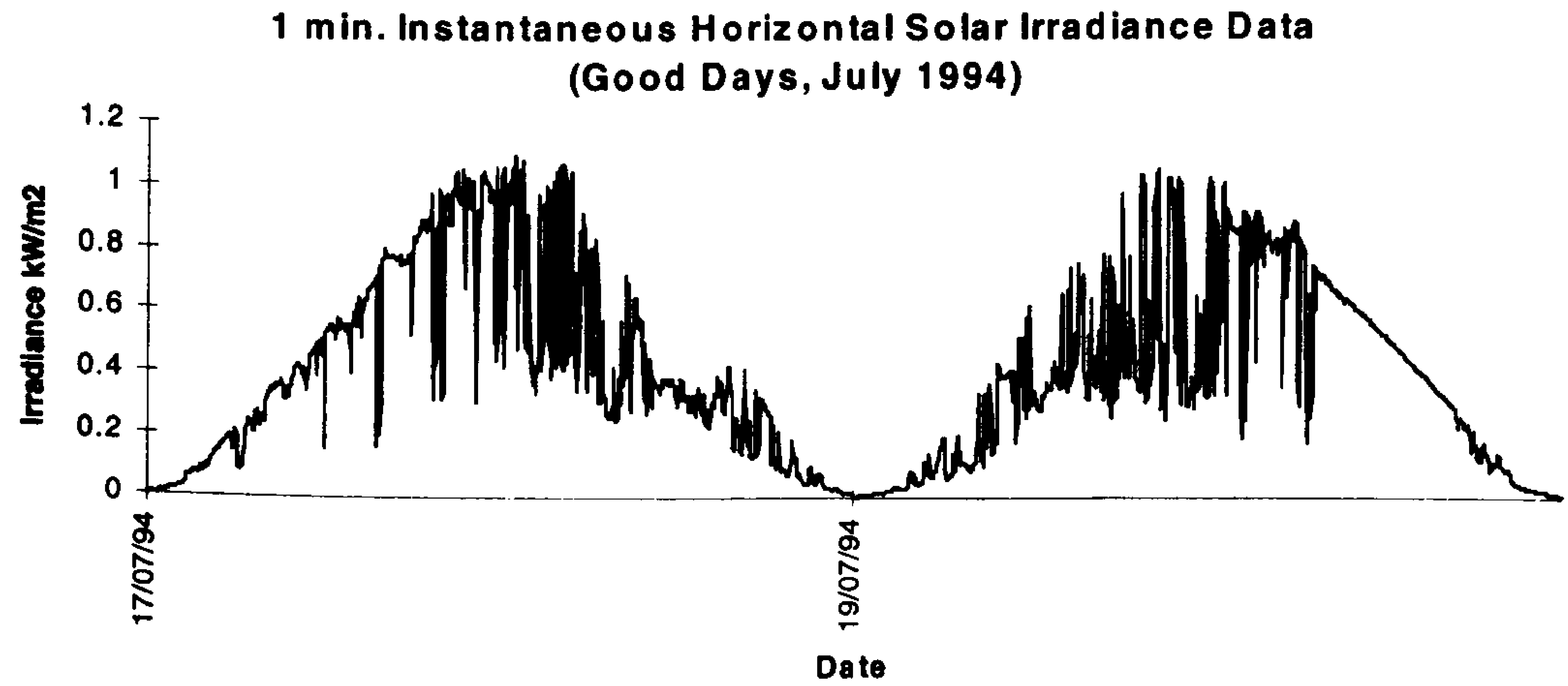
(a)

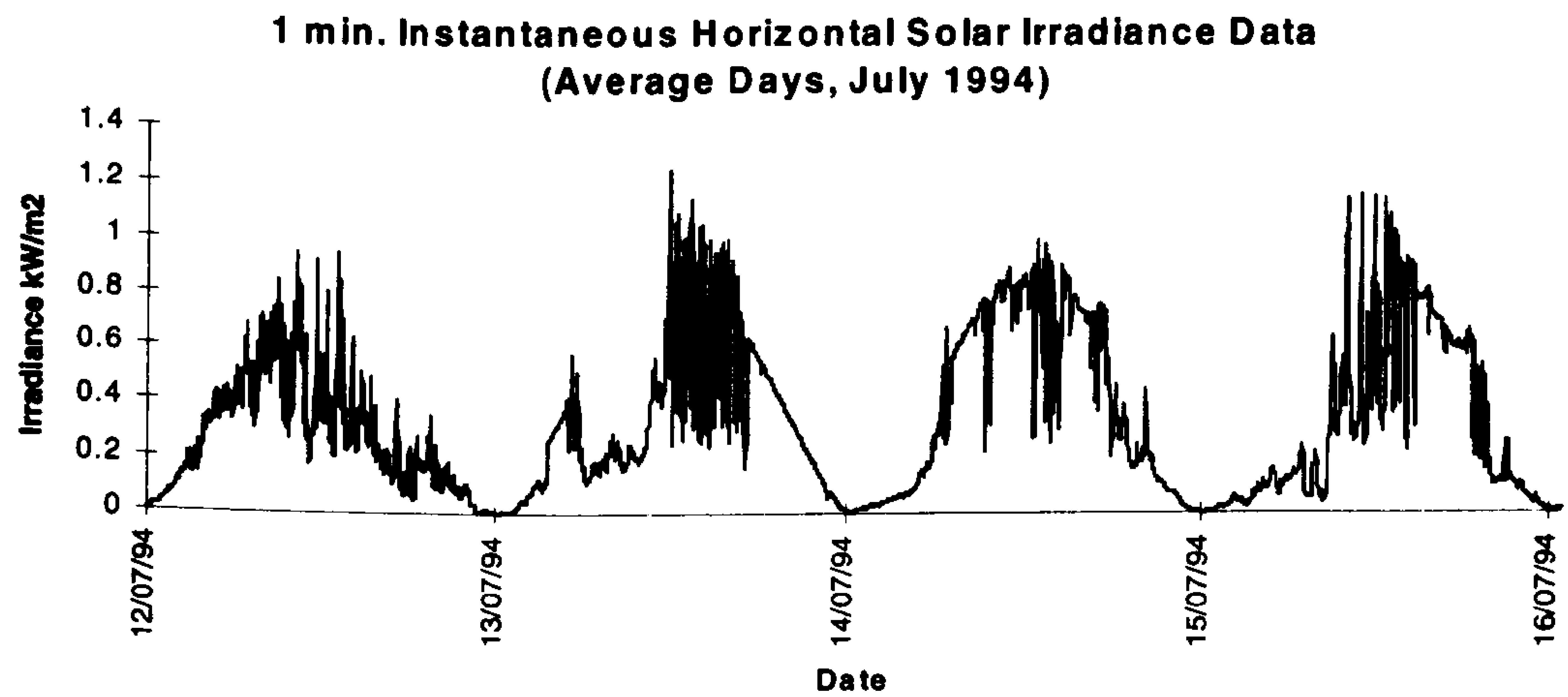
	1 minute instantaneous Horizontal Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(3,1,0)	93	(3,1,0)	99
10	(4,1,0)	94	(2,1,0)	98
11	(2,1,0)	92	(1,1,0	98
12	(4,1,0)	91	(3,1,0)	98
13	(4,1,0)	75	(4,1,0)	96
14	(3,1,0)	95	(3,1,0)	99
15	(2,1,0)	90	(2,1,0)	98
16	(2,1,0)	87	(2,1,0)	97
17	(4,1,0)	88	(3,1,0)	97
18	(4,1,0)	94	(1,1,0)	94
19	(4,1,0)	83	(4,1,0)	96

(b)

	1 minute instantaneous Vertical Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(3,1,0)	91	(2,1,0)	99
10	(3,1,0)	98	(3,1,0)	99
11	(2,1,0)	92	(2,1,0)	99
12	(4,1,0)	90	(2,1,0)	98
13	(4,1,0)	79	(3,1,0)	97
14	(4,1,0)	96	(2,1,0)	99
15	(2,1,0)	91	(2,1,0)	98
16	(2,1,0)	88	(2,1,0)	98
17	(4,1,0)	89	(3,1,0)	98
18	(4,1,0)	95	(1,1,0)	99
19	(4,1,0)	89	(3,1,0)	98

Figure 5.6.1 Horizontal Solar Irradiance for 1 minute instantaneous data





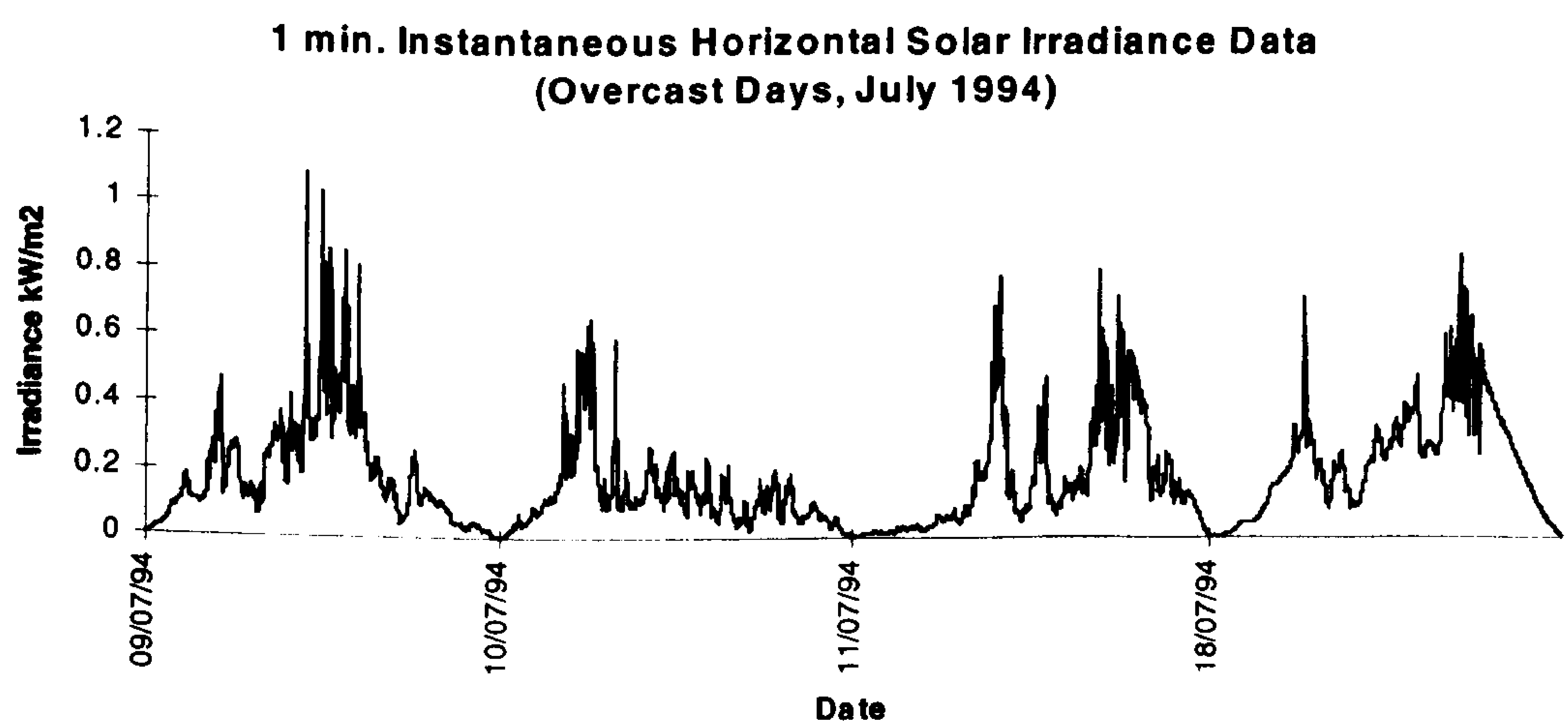
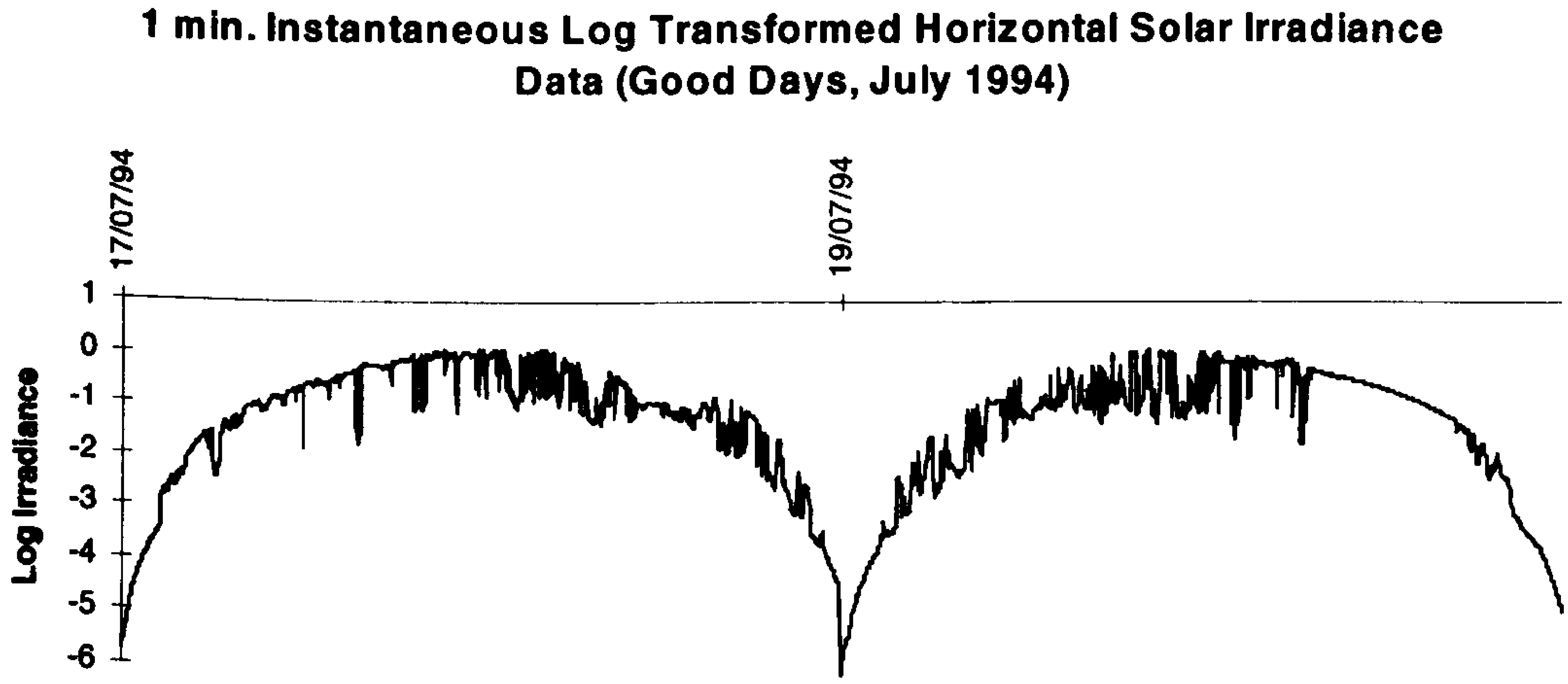
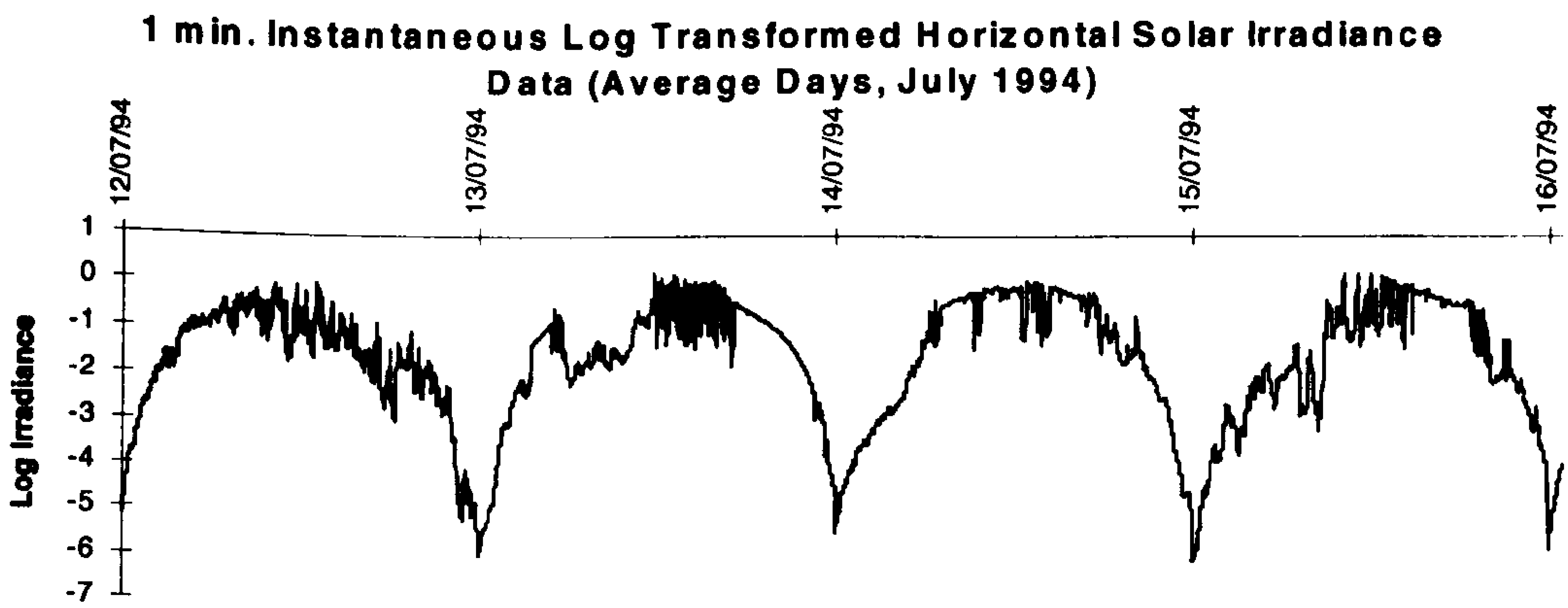


Figure 5.6.2 Log transformed Horizontal Solar Irradiance for 1 minute instantaneous data





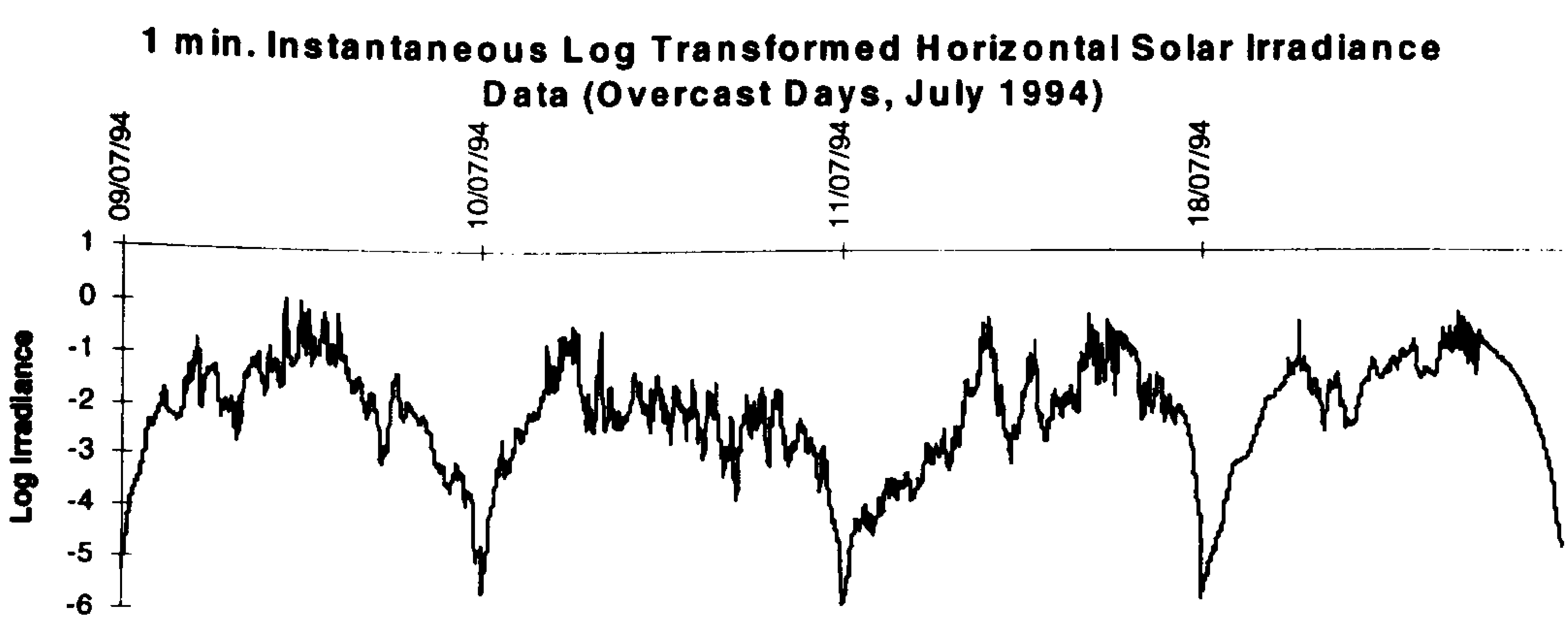
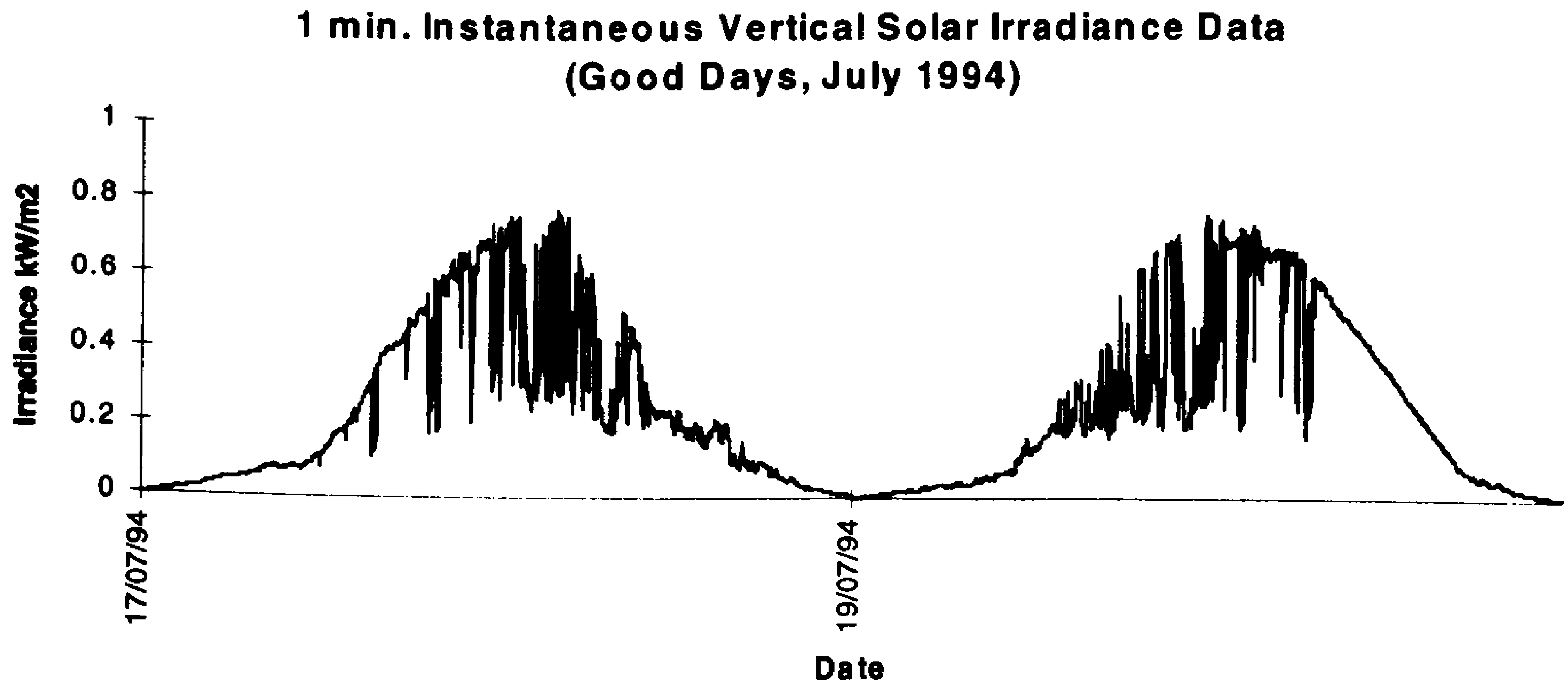
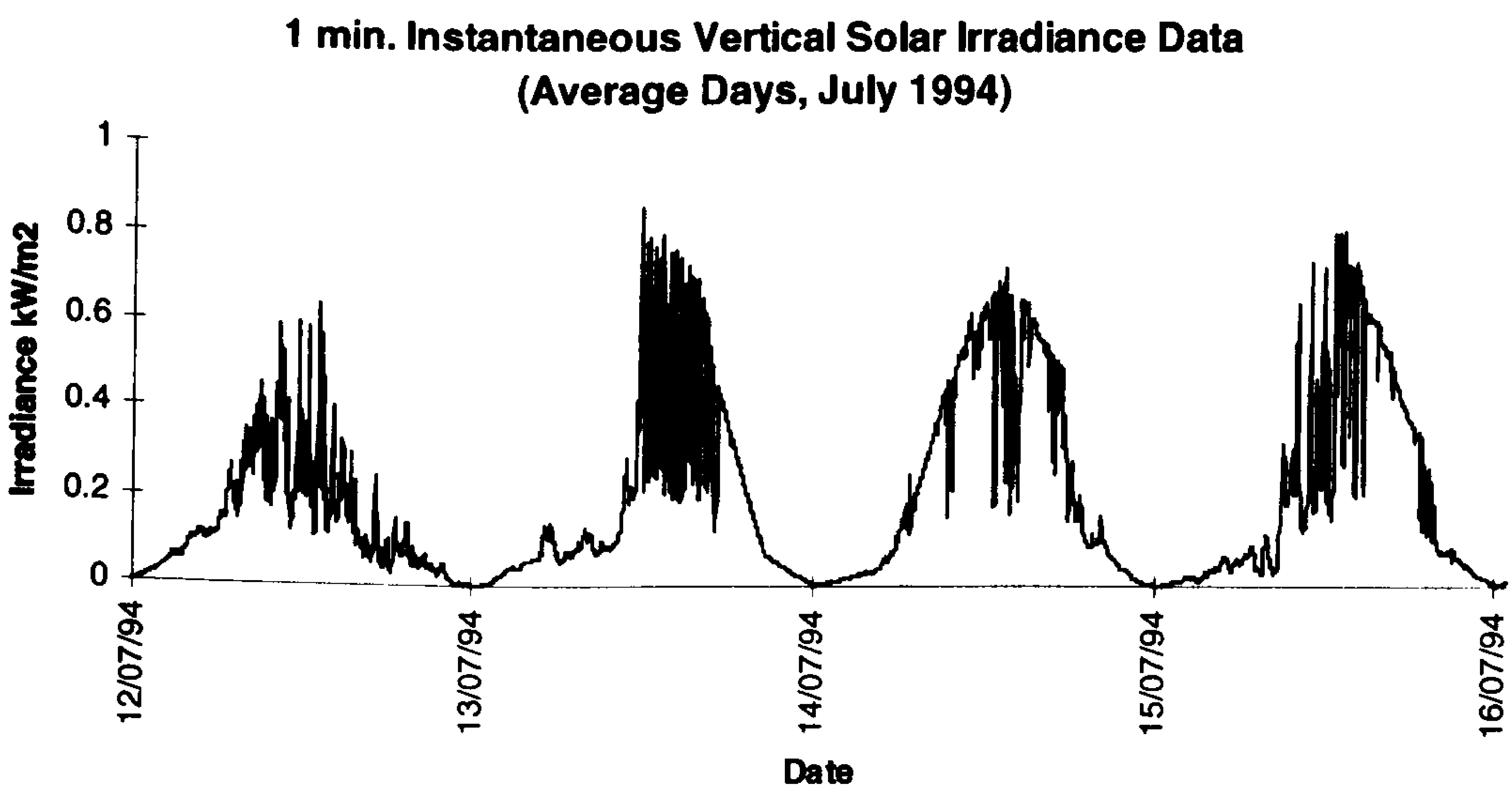


Figure 5.6.3 Vertical Solar Irradiance for 1 minute instantaneous data





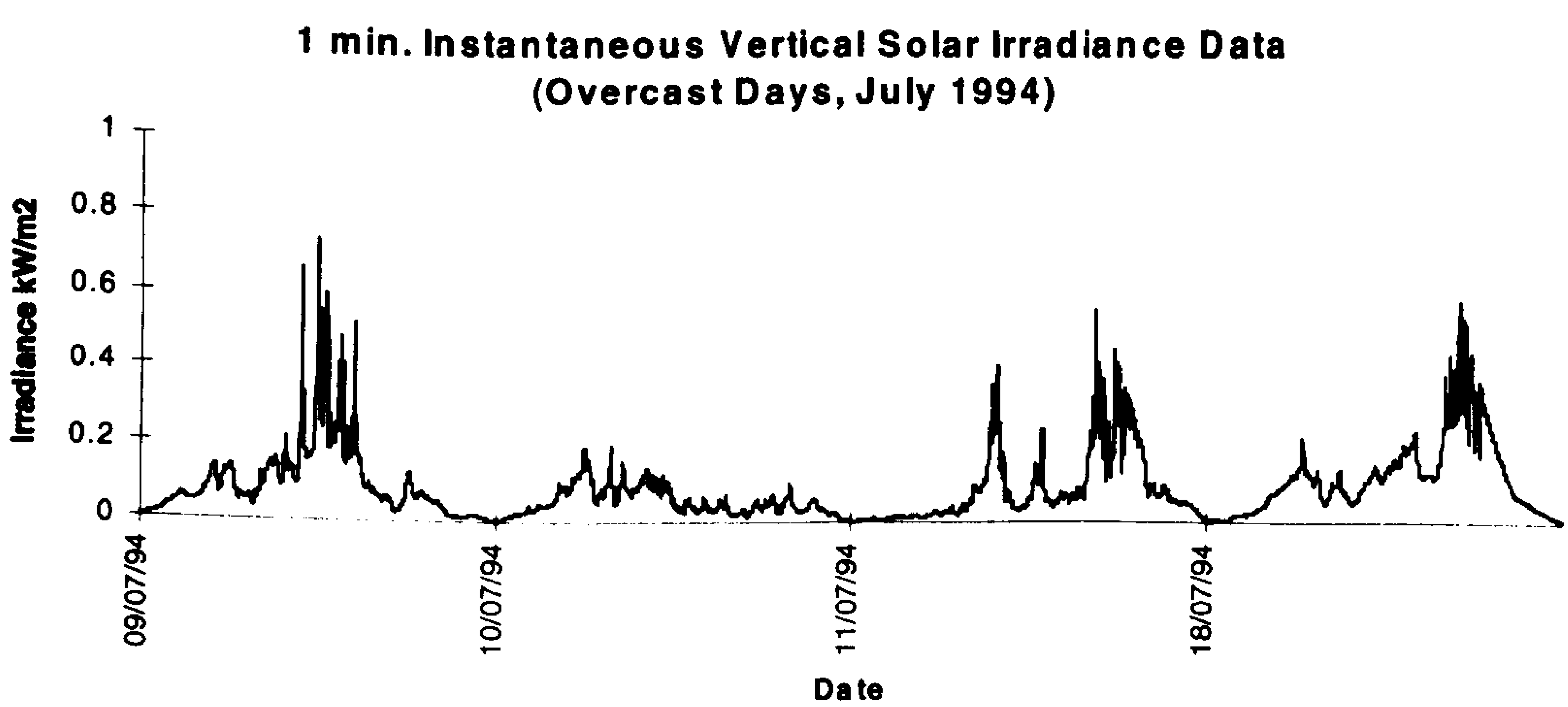
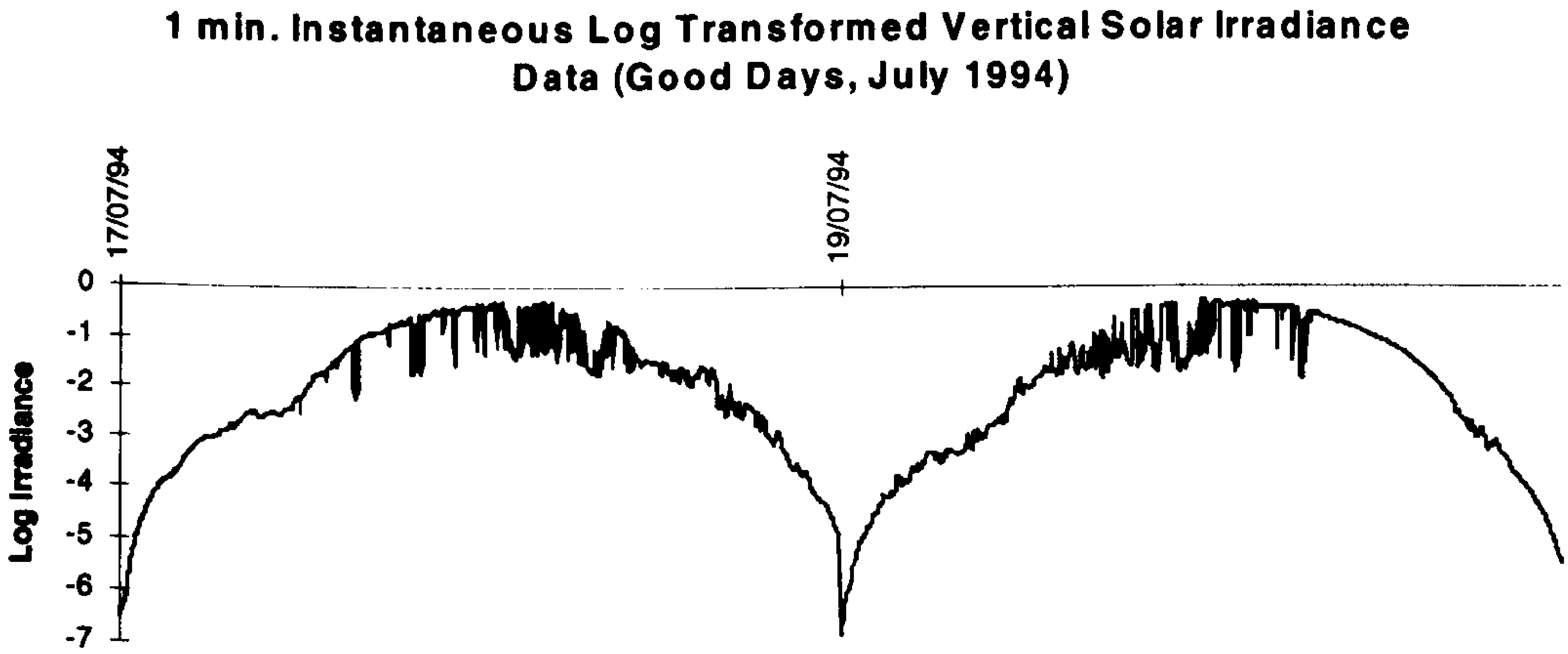
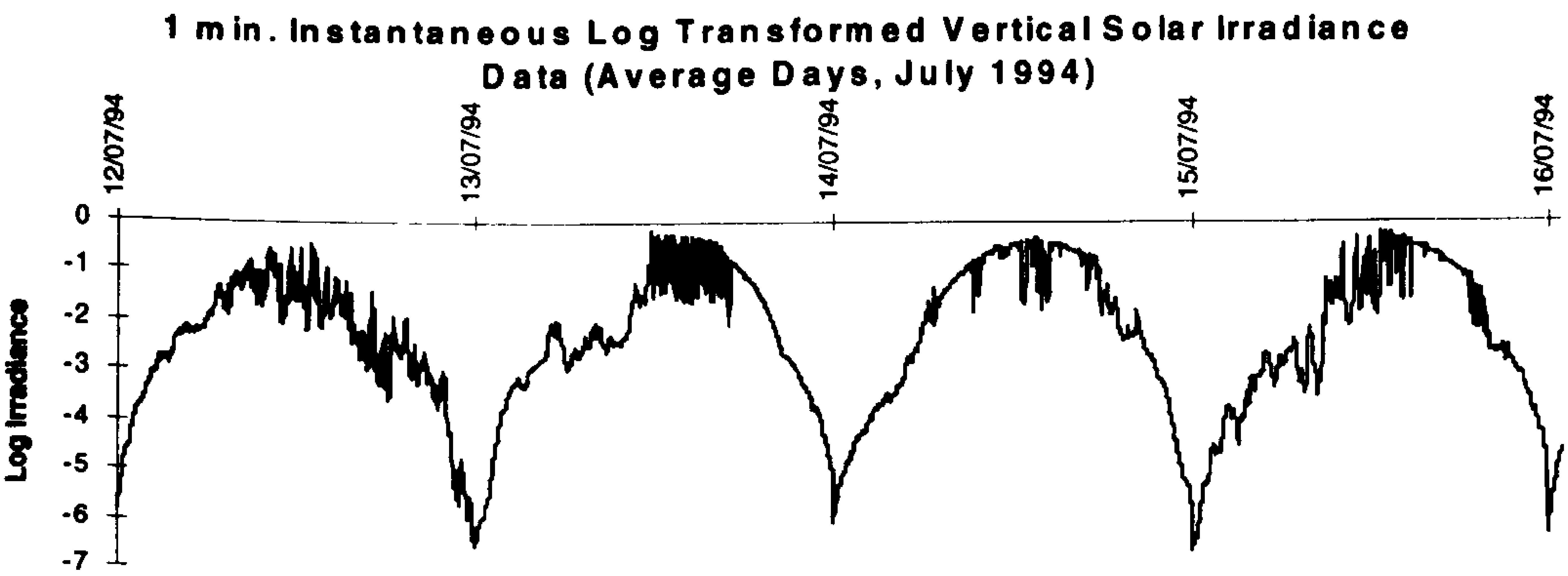
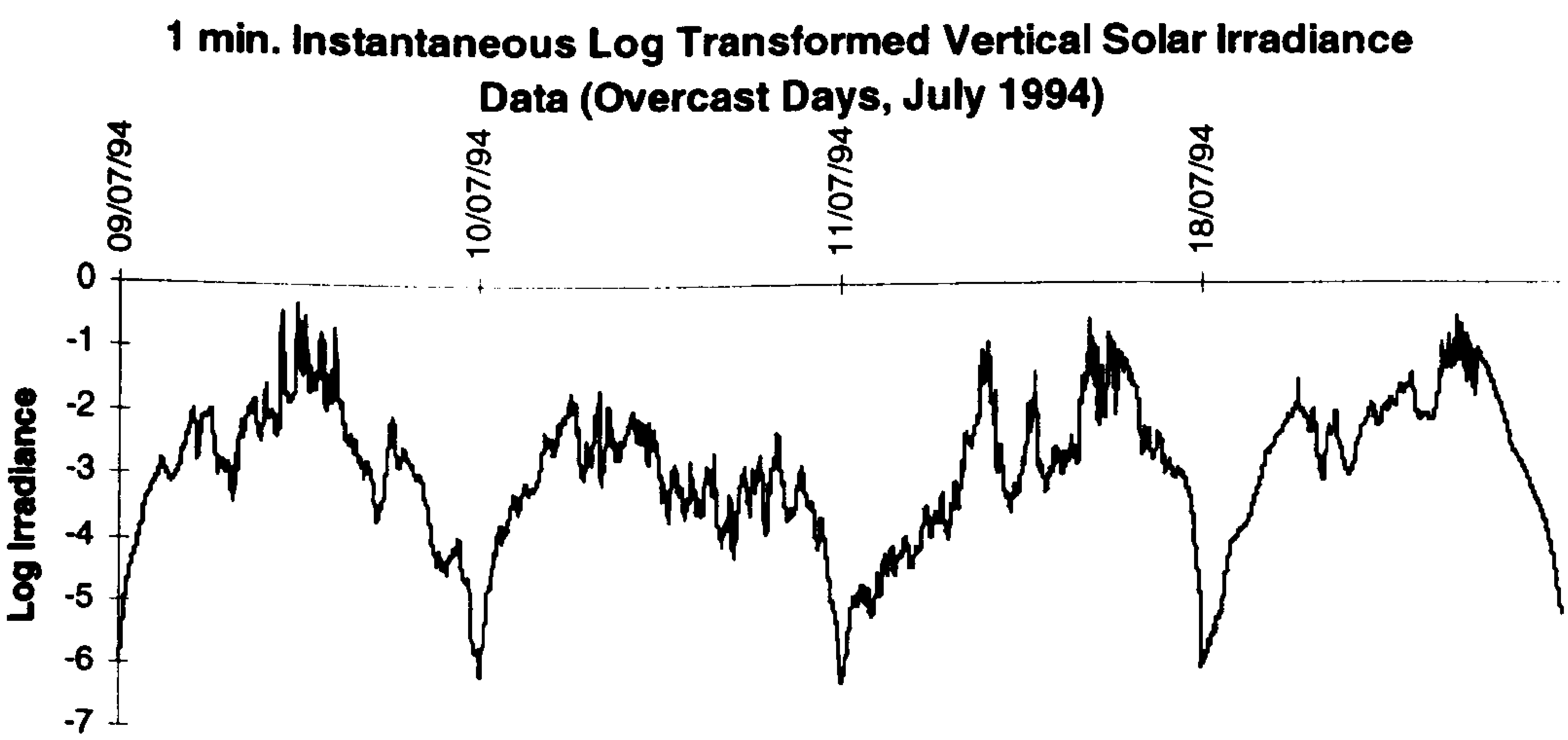


Figure 5.6.4 Log transformed Vertical Solar Irradiance for 1 minute instantaneous data







5.7. Five minute instantaneous - July 1994

The 5 minute instantaneous Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data for the three types of day, Good, Average and Overcast, are displayed in Figure 5.7.1, Figure 5.7.2, Figure 5.7.3 and Figure 5.7.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.7.1(a), Table 5.7.2(a), Table 5.7.3(a) and Table 5.7.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.7.1(b), Table 5.7.2(b), Table 5.7.3(b) and Table 5.7.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.7.5.

Table 5.7.1 Horizontal Solar Irradiance - 5 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.1950	0.1625	0.0053	1.0930
10	0.1322	0.1061	0.0037	0.5736
11	0.1686	0.1596	0.0030	0.6190
12	0.2735	0.2053	0.0053	0.9354
13	0.3289	0.2566	0.0025	1.1460
14	0.3906	0.3206	0.0042	1.0000
15	0.3190	0.3031	0.0023	1.0800
16	0.3335	0.2572	0.0030	1.2350
17	0.4206	0.3072	0.0032	1.1000
18	0.2225	0.1442	0.0035	0.6708
19	0.3932	0.2964	0.0021	1.0410
Overall	0.2889	0.2572	0.0021	1.2350

b)

$2/\sqrt{198} = 0.142$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.821	0.723	0.683	0.653	0.821	0.149	0.175	0.097
10	0.837	0.739	0.653	0.574	0.837	0.130	0.022	-0.006
11	0.888	0.828	0.758	0.698	0.888	0.191	-0.033	0.003
12	0.869	0.793	0.753	0.686	0.869	0.154	0.150	-0.065
13	0.771	0.699	0.667	0.641	0.771	0.258	0.182	0.116
14	0.910	0.886	0.877	0.851	0.910	0.333	0.237	0.031
15	0.869	0.776	0.778	0.775	0.869	0.084	0.361	0.109
16	0.778	0.684	0.616	0.537	0.778	0.200	0.093	-0.011
17	0.826	0.808	0.763	0.734	0.826	0.398	0.123	0.069
18	0.947	0.912	0.878	0.841	0.947	0.145	0.027	-0.037
19	0.825	0.738	0.773	0.751	0.825	0.181	0.404	0.076

Table 5.7.2 Log Transformed Horizontal Solar Irradiance - 5 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.0421	1.0304	-5.2400	0.0889
10	-2.3298	0.8647	-5.5994	-0.5558
11	-2.3289	1.1951	-5.8091	-0.3696
12	-1.7435	1.1714	-5.2400	-0.0668
13	-1.5810	1.2122	-5.9915	0.1363
14	-1.5960	1.4260	-5.4730	0.0000
15	-1.8185	1.3904	-6.0748	0.0770
16	-1.5741	1.2127	-5.8091	0.2111
17	-1.3223	1.2039	-5.7446	0.0953
18	-1.8989	1.1389	-5.6550	-0.3993
19	-1.4763	1.3461	-6.1658	0.0402
Overall	-1.7919	1.2497	-6.1658	0.2111

b)

$2/\sqrt{198} = 0.142$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.927	0.852	0.784	0.725	0.927	-0.057	0.012	0.026
10	0.877	0.758	0.653	0.579	0.877	-0.051	-0.004	0.072
11	0.948	0.899	0.853	0.809	0.948	0.008	0.003	0.002
12	0.918	0.855	0.799	0.750	0.918	0.076	0.027	0.019
13	0.917	0.857	0.807	0.760	0.917	0.099	0.045	0.013
14	0.951	0.916	0.882	0.847	0.951	0.111	0.019	-0.017
15	0.938	0.881	0.835	0.793	0.938	0.017	0.058	0.014
16	0.896	0.831	0.775	0.722	0.896	0.139	0.046	0.008
17	0.901	0.847	0.794	0.747	0.901	0.185	0.026	0.021
18	0.951	0.904	0.856	0.808	0.951	-0.016	-0.024	-0.030
19	0.919	0.862	0.826	0.786	0.919	0.109	0.132	-0.006

Table 5.7.3 Vertical Solar Irradiance - 5 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.0974	0.0978	0.0026	0.6630
10	0.0552	0.0376	0.0022	0.1768
11	0.0870	0.0947	0.0019	0.4158
12	0.1393	0.1213	0.0026	0.5773
13	0.1876	0.2004	0.0015	0.7961
14	0.2473	0.2295	0.0024	0.7236
15	0.2048	0.2232	0.0013	0.8004
16	0.1808	0.1768	0.0019	0.7942
17	0.2326	0.2129	0.0015	0.7740
18	0.1137	0.0907	0.0026	0.4381
19	0.2506	0.2350	0.0011	0.7636
Overall	0.1633	0.1816	0.0011	0.8004

b)

$2/\sqrt{198} = 0.142$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.805	0.699	0.650	0.633	0.805	0.145	0.154	0.144
10	0.897	0.790	0.699	0.656	0.897	-0.070	0.019	0.085
11	0.892	0.834	0.765	0.705	0.892	0.182	-0.031	-0.002
12	0.872	0.791	0.764	0.701	0.872	0.129	0.218	-0.086
13	0.762	0.738	0.719	0.696	0.762	0.295	0.216	0.126
14	0.918	0.892	0.884	0.854	0.918	0.312	0.242	-0.006
15	0.885	0.795	0.805	0.805	0.885	0.056	0.424	0.078
16	0.818	0.727	0.663	0.579	0.818	0.174	0.092	-0.049
17	0.833	0.828	0.783	0.758	0.833	0.437	0.126	0.066
18	0.958	0.932	0.903	0.869	0.958	0.176	-0.012	-0.093
19	0.887	0.823	0.836	0.819	0.887	0.169	0.382	0.061

Table 5.7.4 Log Transformed Vertical Solar Irradiance - 5 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.8192	1.0989	-5.9522	-0.4110
10	-3.1620	0.8078	-6.1193	-1.7327
11	-3.0603	1.2199	-6.2659	-0.8776
12	-2.4885	1.2192	-5.9522	-0.5494
13	-2.3435	1.3571	-6.5023	-0.2280
14	-2.1830	1.5410	-6.0320	-0.3240
15	-2.4070	1.5010	-6.6450	-0.2230
16	-2.2998	1.2575	-6.2659	-0.2304
17	-2.0651	1.3189	-6.5023	-0.2562
18	-2.6391	1.1683	-5.9522	-0.8253
19	-2.1100	1.4760	-6.8120	-0.2700
Overall	-2.5070	1.3305	-6.8125	-0.2226

b)

$2/\sqrt{198} = 0.142$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.937	0.871	0.814	0.765	0.937	-0.052	0.038	0.032
10	0.901	0.795	0.704	0.636	0.901	-0.094	0.026	0.064
11	0.956	0.914	0.874	0.836	0.956	0.005	0.003	-0.003
12	0.929	0.868	0.820	0.774	0.929	0.029	0.075	-0.008
13	0.938	0.895	0.858	0.822	0.938	0.122	0.051	0.011
14	0.958	0.926	0.898	0.868	0.958	0.103	0.039	-0.018
15	0.951	0.905	0.871	0.839	0.951	0.017	0.092	0.017
16	0.925	0.867	0.816	0.768	0.925	0.083	0.031	-0.003
17	0.933	0.892	0.848	0.812	0.933	0.162	-0.008	0.039
18	0.963	0.924	0.883	0.843	0.963	-0.037	-0.048	-0.021
19	0.943	0.899	0.870	0.839	0.943	0.090	0.125	-0.002

Table 5.7.5 Summary information from fitted ARIMA models

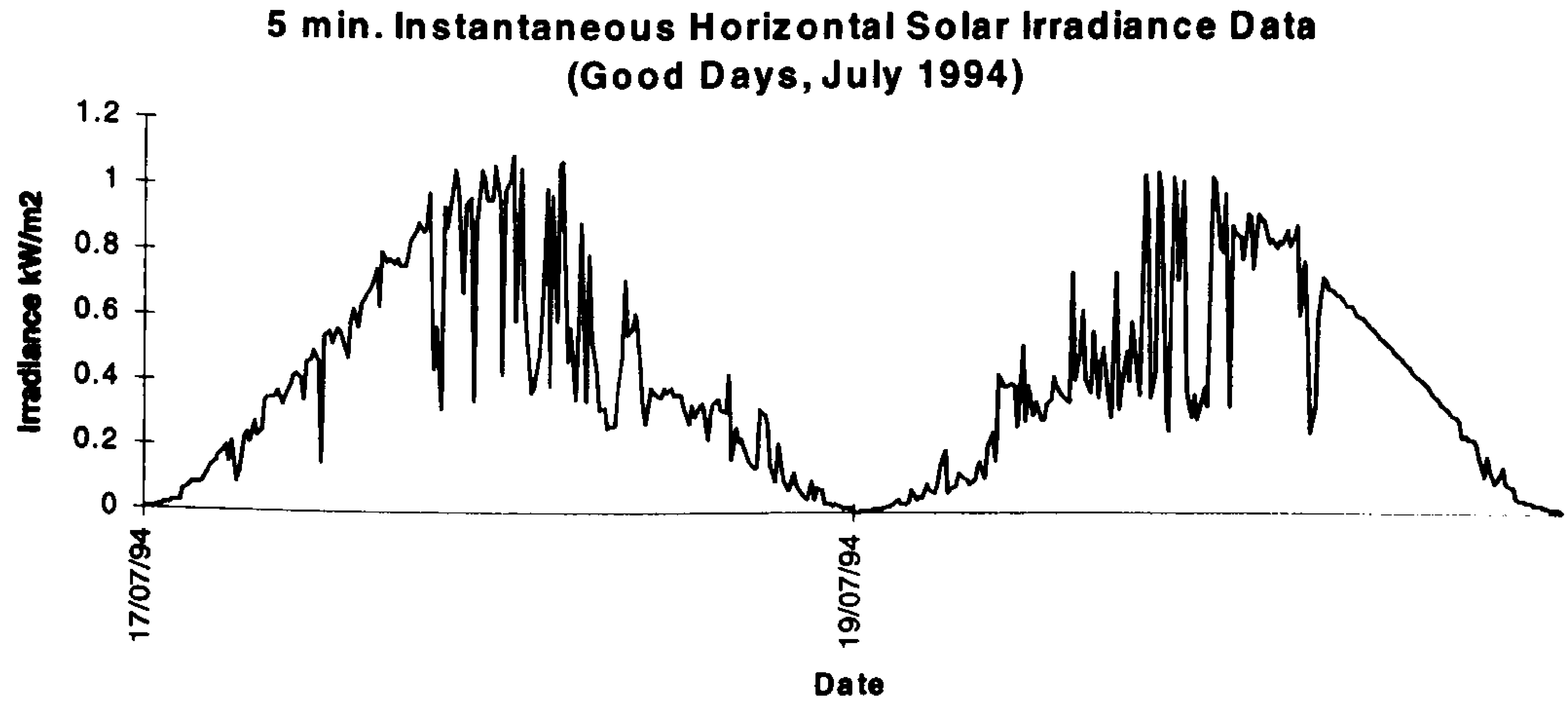
(a)

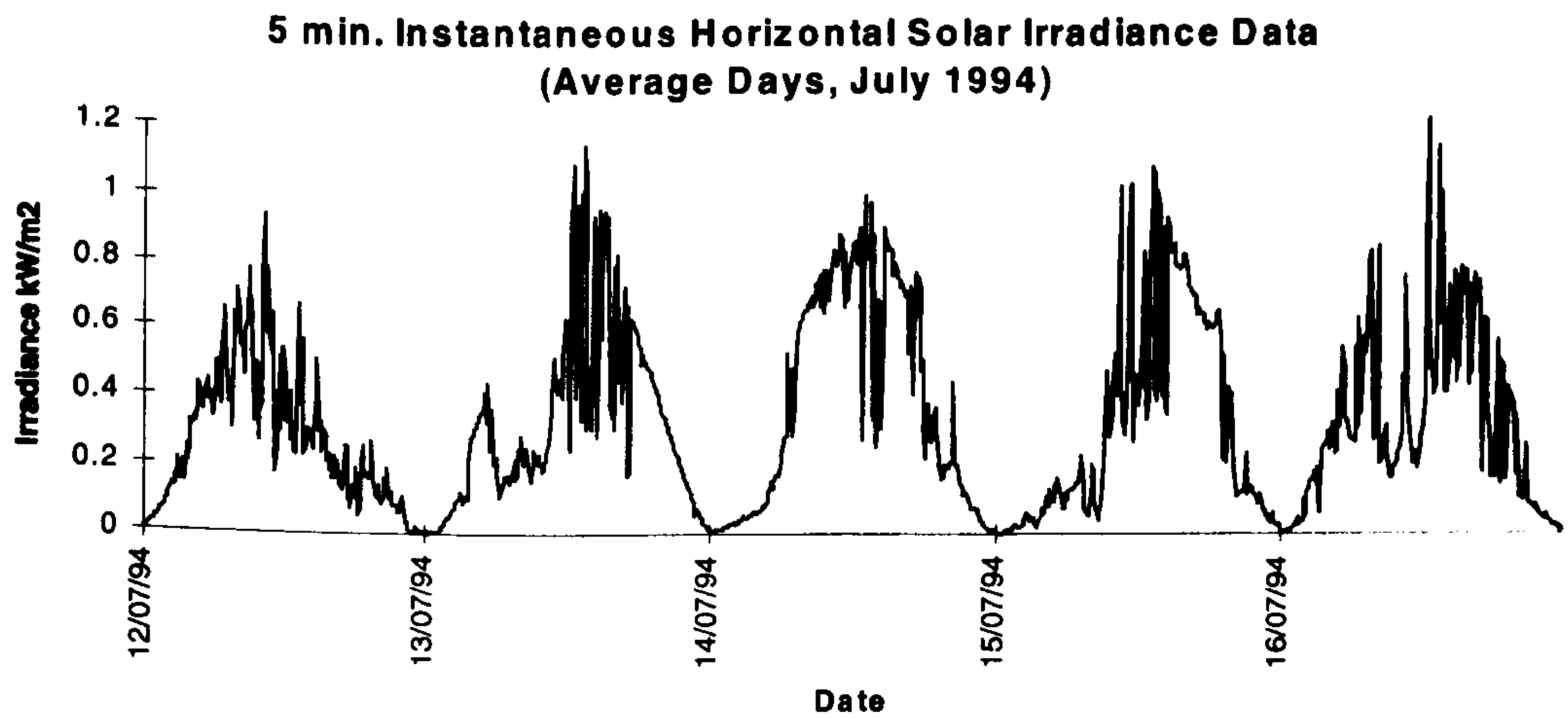
	5 minute instantaneous Horizontal Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(1,0,0)	68		
10	(1,1,0)	70		
11	(1,1,0)	80		
12	(1,1,0)	76	(1,1,0)	92
13	(4,1,0)	66	(1,1,0)	93
14	(2,1,0)	87	(1,1,0)	97
15	(1,1,0)	75		
16	(1,1,0)	60	(1,1,0)	89
17	(2,1,0)	75	(1,1,0)	92
18	(1,1,0)	92	(1,1,0)	98
19	(2,1,0)	75	(1,1,0)	93

(b)

	5 minute instantaneous Vertical Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(1,0,0)	65		
10	(1,0,0)	82	(3,1,0)	91
11	(1,1,0)	80		
12	(1,1,0)	76		
13	(4,1,0)	69	(2,1,0)	95
14	(2,1,0)	87	(1,1,0)	97
15	(2,1,0)	83	(2,1,0)	95
16	(1,1,0)	67	(1,1,0)	93
17	(2,1,0)	76	(1,1,0)	95
18	(1,1,0)	93	(2,1,0)	99
19	(2,1,0)	83	(2,1,0)	96

Figure 5.7.1 Horizontal Solar Irradiance for 5 minute instantaneous





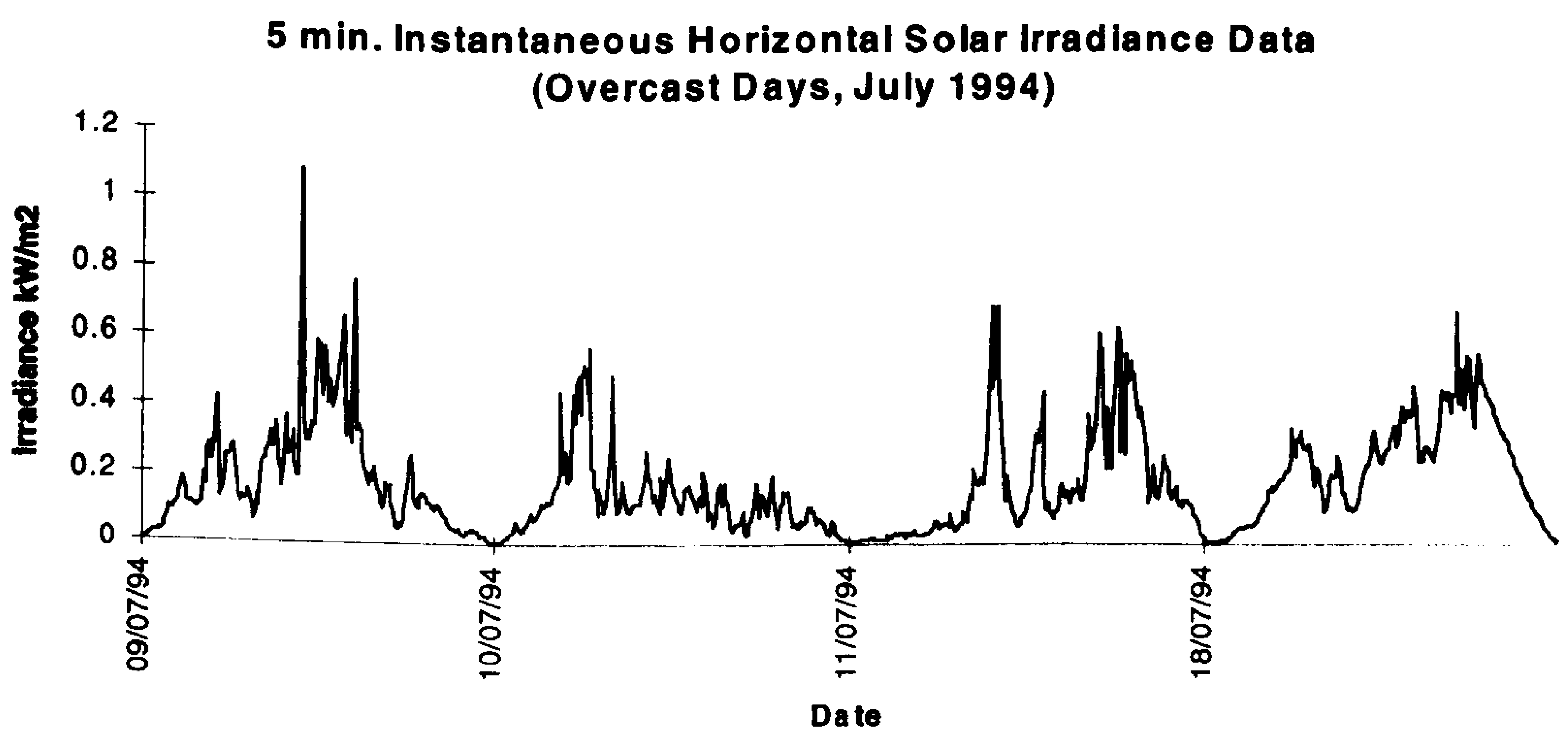
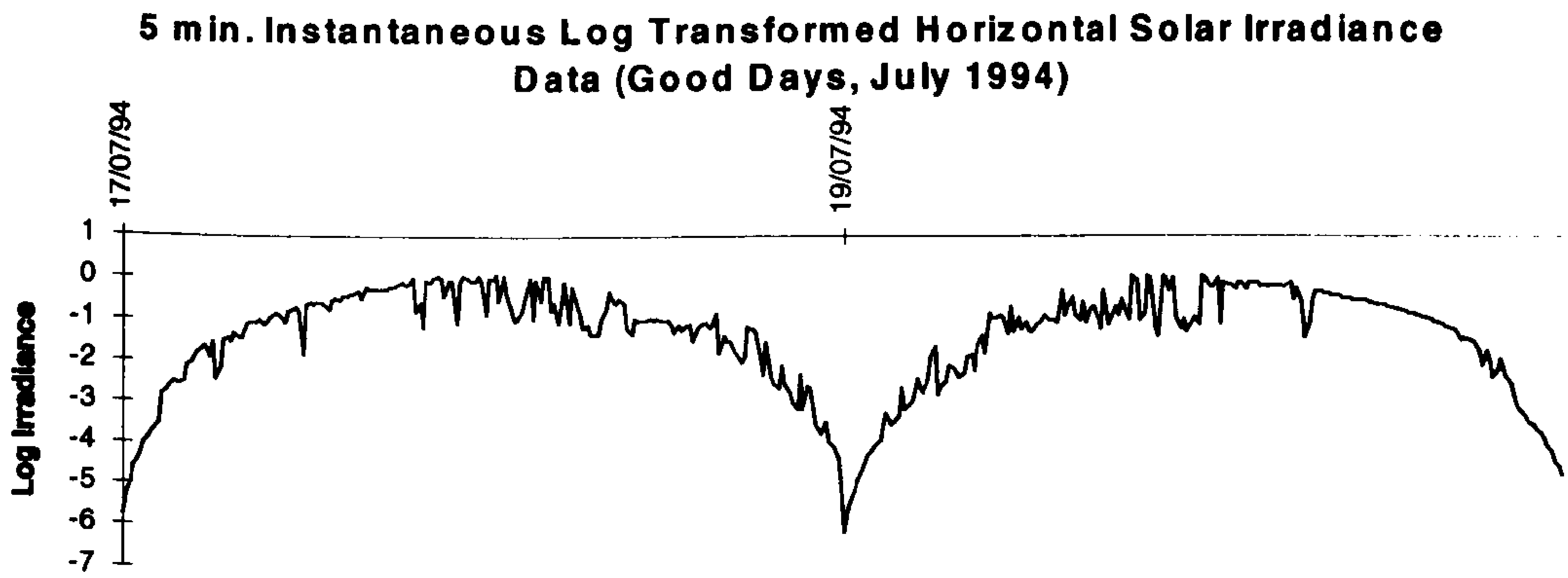
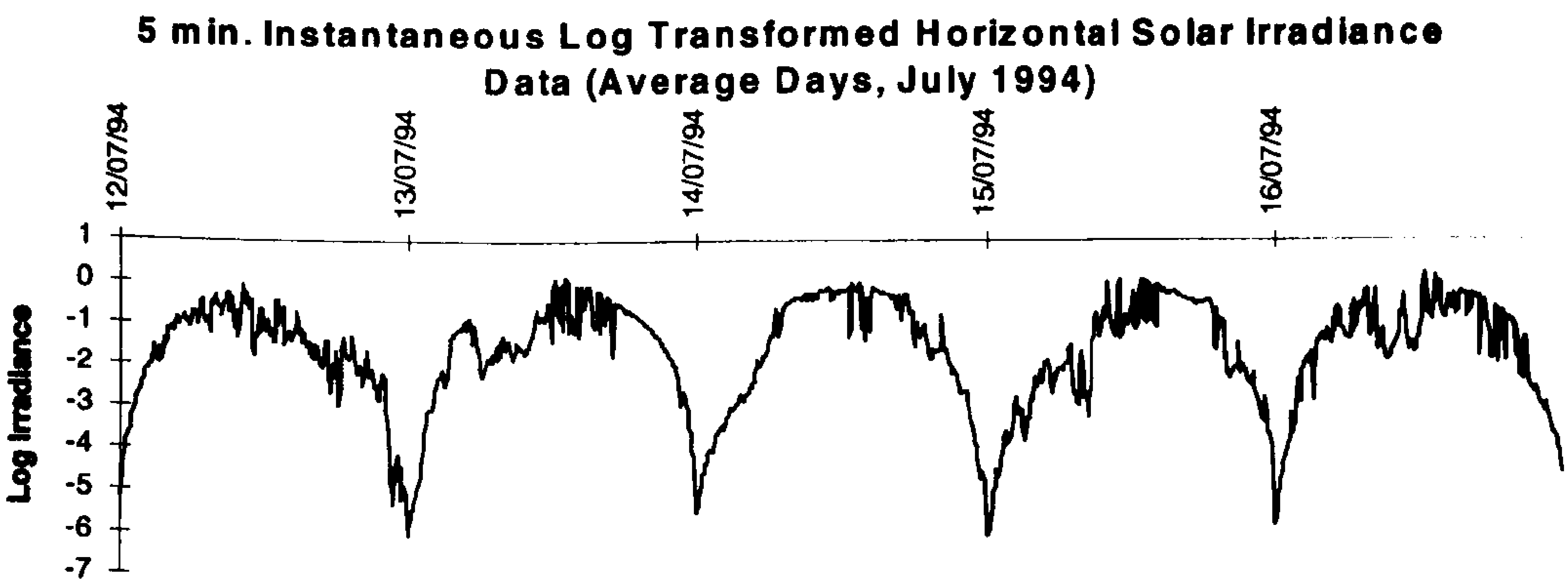


Figure 5.7.2 Log transformed Horizontal Solar Irradiance for 5 minute instantaneous





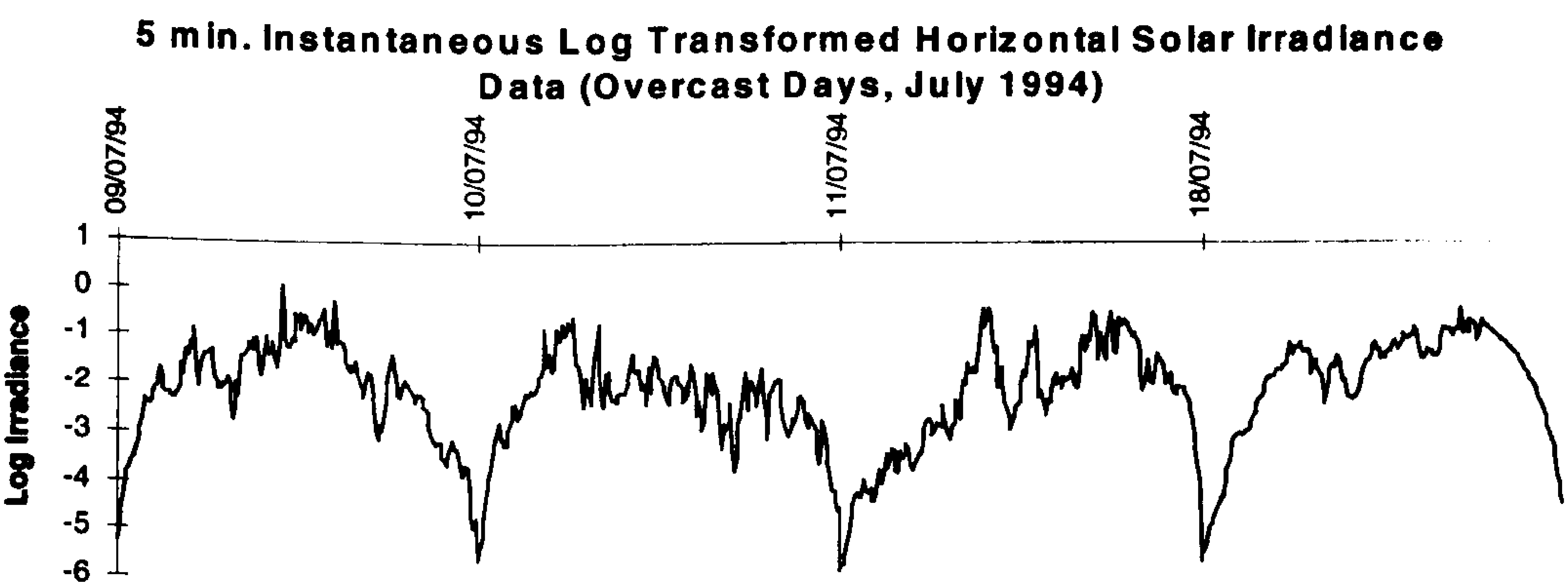
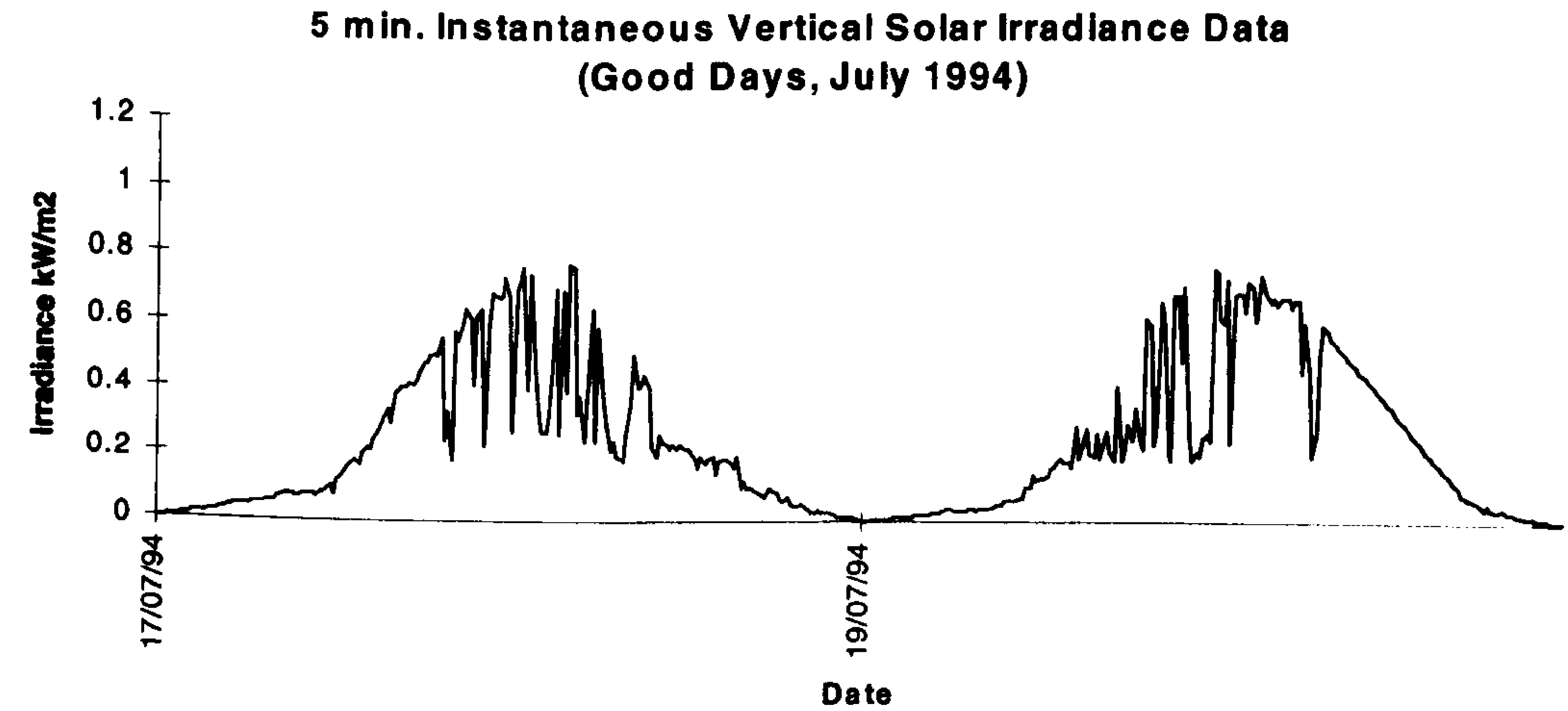
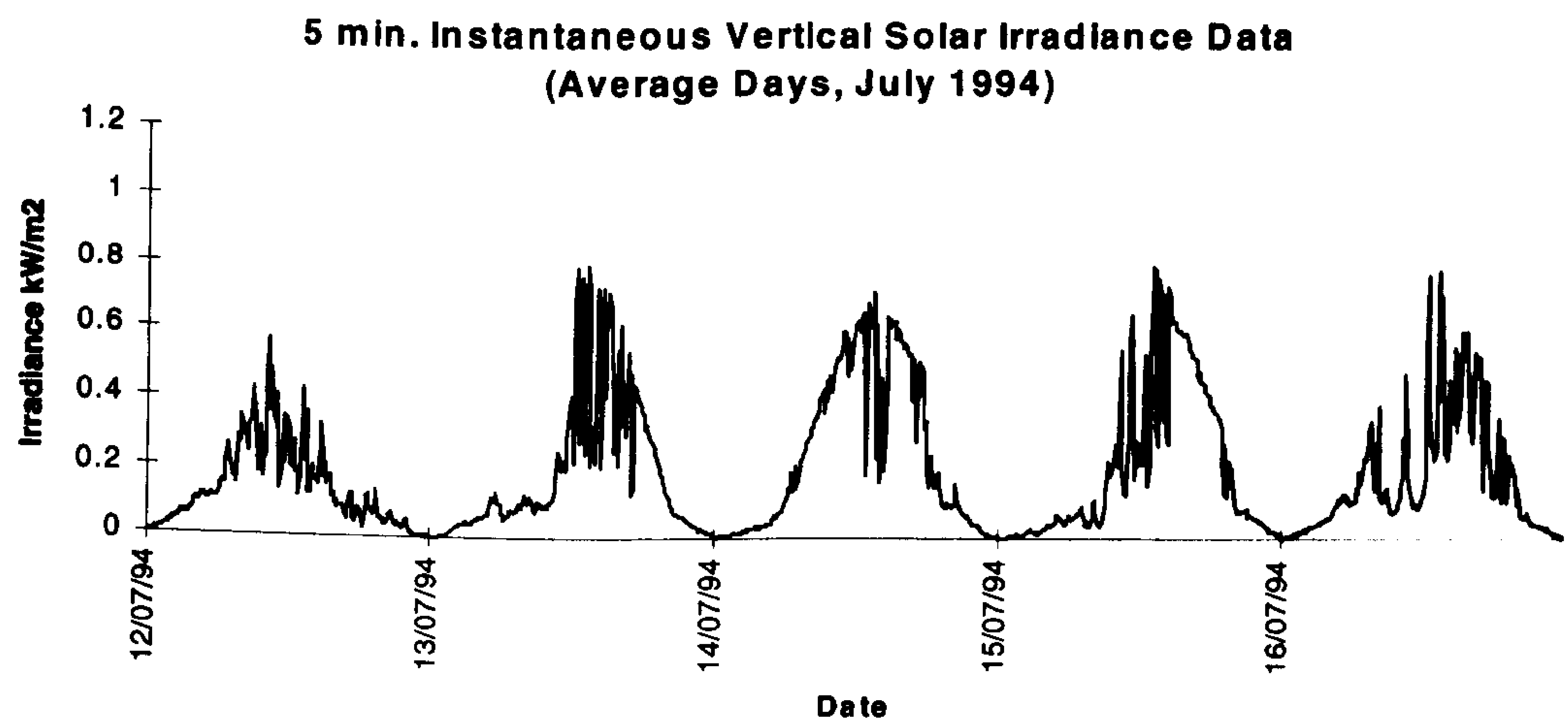


Figure 5.7.3 Vertical Solar Irradiance for 5 minute instantaneous





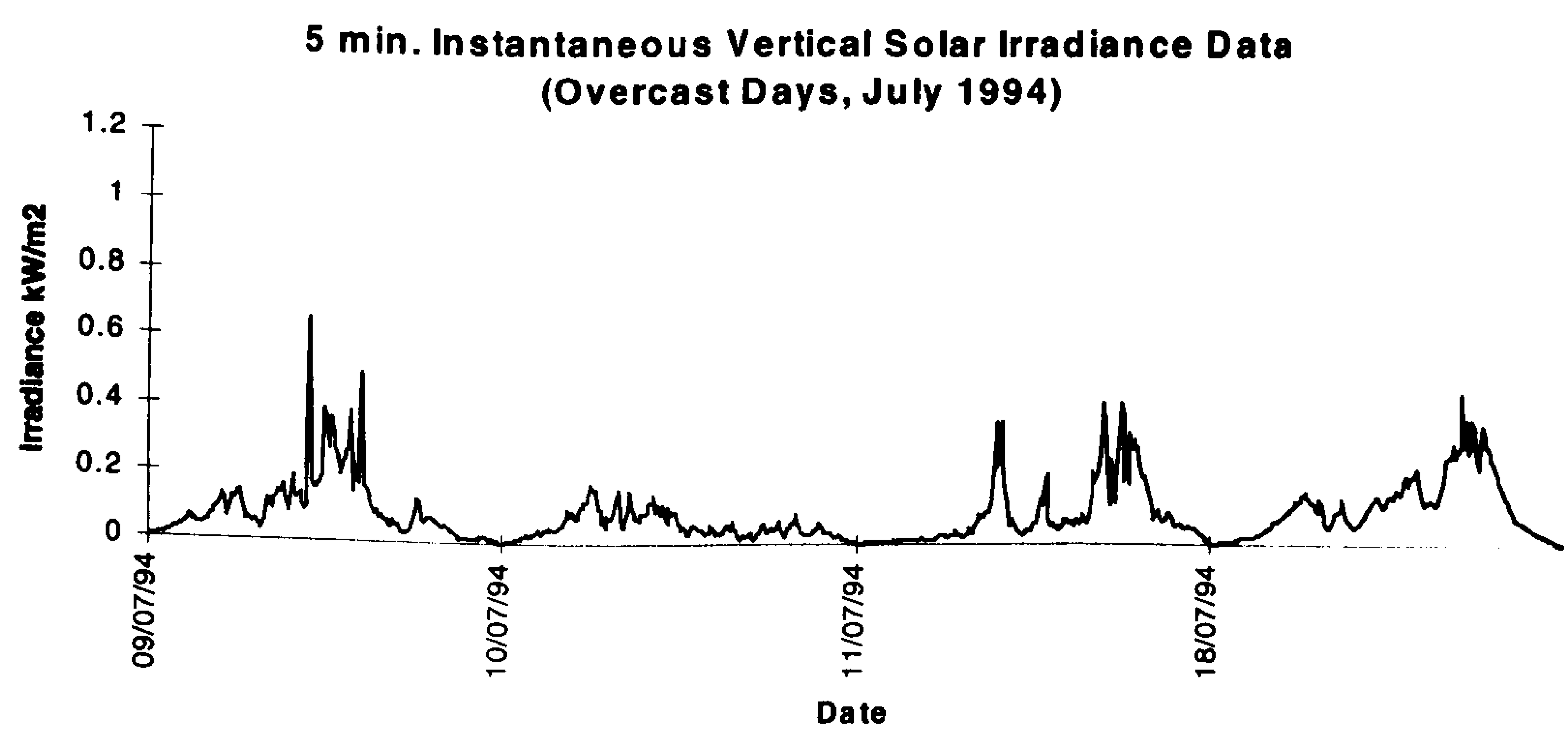
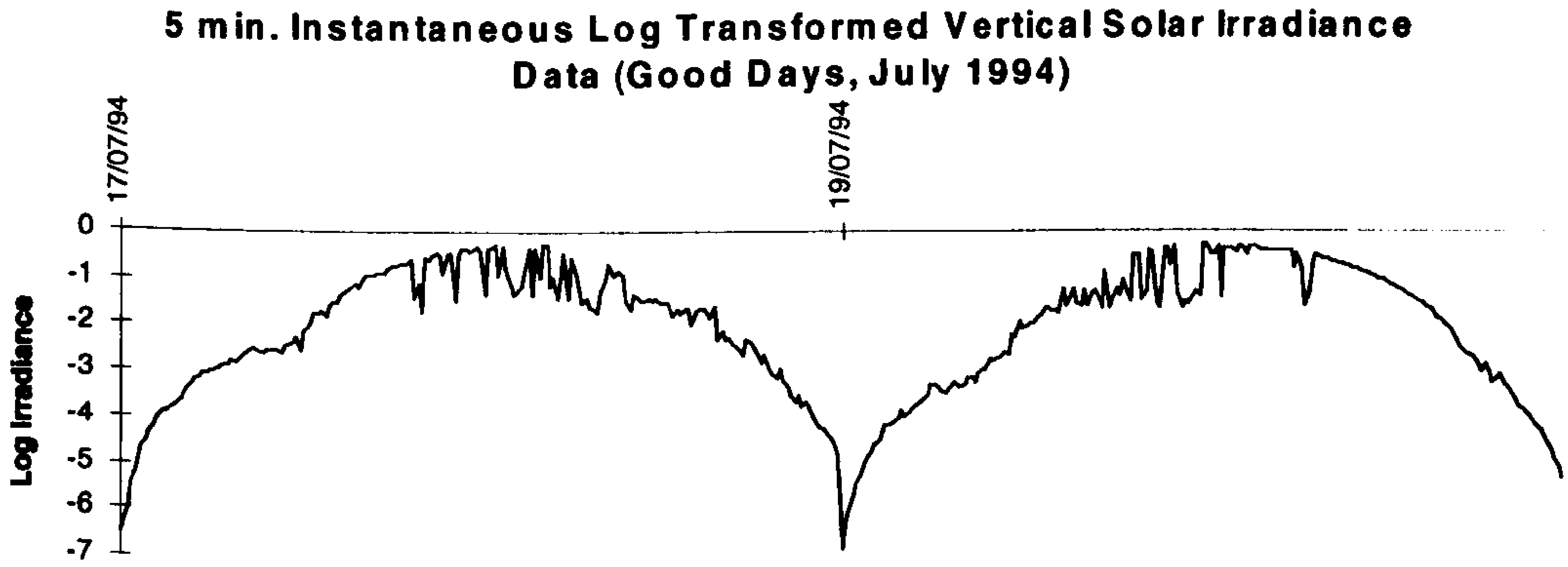
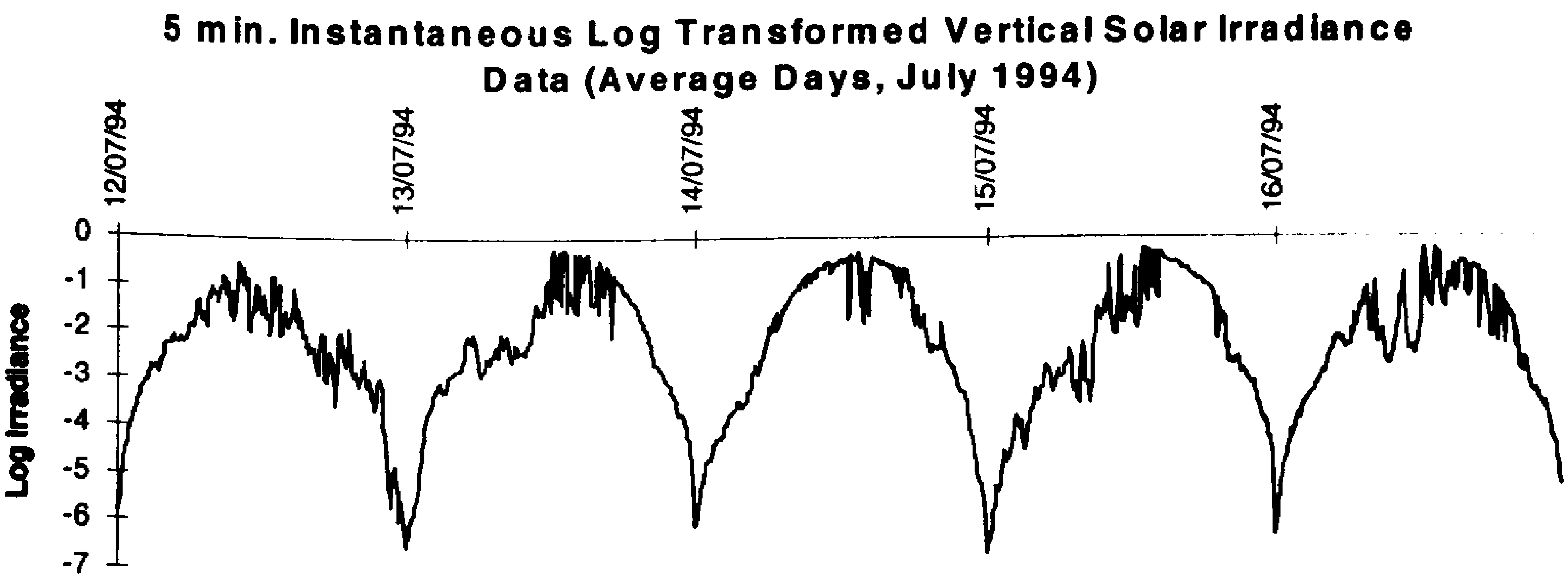
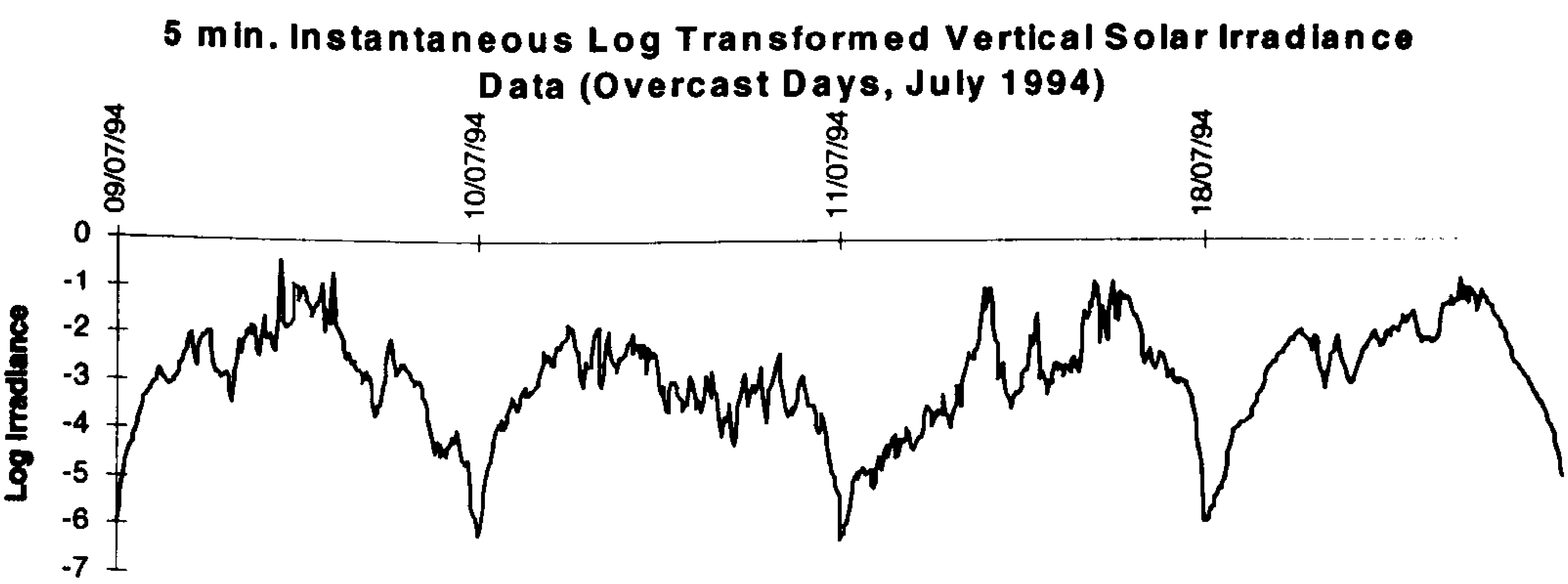


Figure 5.7.4 Log transformed Vertical Solar Irradiance for 5 minute instantaneous







5.8. Ten minute instantaneous - July 1994

The 10 minute instantaneous Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data for the three types of day, Good, Average and Overcast, are displayed in Figure 5.8.1, Figure 5.8.2, Figure 5.8.3 and Figure 5.8.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.8.1(a), Table 5.8.2(a), Table 5.8.3(a) and Table 5.8.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.8.1(b), Table 5.8.2(b), Table 5.8.3(b) and Table 5.8.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.8.5.

Table 5.8.1 Horizontal Solar Irradiance - 10 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.1971	0.1709	0.0053	1.0930
10	0.1346	0.1089	0.0037	0.5736
11	0.1639	0.1572	0.0030	0.6896
12	0.2742	0.2067	0.0058	0.7981
13	0.3314	0.2578	0.0025	1.0960
14	0.3804	0.3174	0.0042	1.0000
15	0.3258	0.3218	0.0025	1.1170
16	0.3371	0.2603	0.0030	1.2350
17	0.4229	0.3136	0.0032	1.0690
18	0.2229	0.1441	0.0035	0.5470
19	0.3943	0.2923	0.0021	1.0410
Overall	0.2891	0.2583	0.0021	1.2350

b)

$2/\sqrt{99} = 0.201$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.679	0.603	0.589	0.637	0.679	0.264	0.217	0.283
10	0.750	0.575	0.493	0.408	0.750	0.029	0.119	-0.011
11	0.799	0.633	0.536	0.475	0.799	-0.013	0.093	0.062
12	0.793	0.682	0.615	0.627	0.793	0.141	0.107	0.238
13	0.682	0.606	0.638	0.645	0.682	0.265	0.309	0.222
14	0.867	0.837	0.787	0.763	0.867	0.344	0.059	0.095
15	0.781	0.716	0.734	0.760	0.781	0.272	0.316	0.285
16	0.647	0.523	0.549	0.512	0.647	0.181	0.276	0.100
17	0.772	0.714	0.649	0.706	0.772	0.292	0.093	0.342
18	0.915	0.853	0.798	0.730	0.915	0.091	0.031	-0.099
19	0.711	0.747	0.659	0.649	0.711	0.487	0.107	0.086

Table 5.8.2 Log Transformed Horizontal Solar Irradiance - 10 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.0410	1.040	-5.2400	0.089
10	-2.3187	0.8842	-5.5994	-0.5558
11	-2.3540	1.1960	-5.8090	-0.3720
12	-1.7490	1.1880	-5.1500	-0.2260
13	-1.5770	1.2580	-5.9910	0.0920
14	-1.6190	1.4200	-5.4730	0.0000
15	-1.8180	1.3880	-5.9910	0.1110
16	-1.5690	1.2290	-5.8090	0.2110
17	-1.3330	1.2320	-5.7450	0.0670
18	-1.9020	1.1550	-5.6550	0.6030
19	-1.4690	1.3580	-6.1660	0.0400
Overall	-1.7967	1.2610	-6.1658	0.2111

b)

$2/\sqrt{99} = 0.201$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.846	0.719	0.647	0.599	0.846	0.011	0.128	0.067
10	0.749	0.571	0.471	0.414	0.749	0.022	0.081	0.071
11	0.900	0.806	0.728	0.667	0.900	-0.020	0.028	0.054
12	0.861	0.748	0.672	0.593	0.861	0.028	0.084	-0.033
13	0.856	0.760	0.676	0.594	0.856	0.099	0.019	-0.027
14	0.912	0.841	0.778	0.727	0.912	0.060	0.018	0.038
15	0.876	0.779	0.732	0.701	0.876	0.054	0.169	0.088
16	0.830	0.717	0.647	0.571	0.830	0.089	0.098	-0.016
17	0.839	0.735	0.657	0.596	0.839	0.104	0.057	0.046
18	0.905	0.812	0.725	0.647	0.905	-0.037	-0.021	-0.002
19	0.857	0.785	0.701	0.636	0.857	0.191	-0.024	0.016

Table 5.8.3 Vertical Solar Irradiance - 10 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.0972	0.1008	0.0026	0.6630
10	0.0553	0.0372	0.0022	0.1626
11	0.0854	0.0949	0.0019	0.4158
12	0.1398	0.1232	0.0026	0.5080
13	0.1897	0.2023	0.0015	0.7933
14	0.2416	0.2273	0.0024	0.6933
15	0.2103	0.2333	0.0015	0.7879
16	0.1809	0.1758	0.0019	0.7807
17	0.2353	0.2169	0.0015	0.7740
18	0.1137	0.0903	0.0026	0.3623
19	0.2476	0.2296	0.0011	0.7522
Overall	0.1630	0.1815	0.0011	0.7933

b)

$2/\sqrt{99} = 0.201$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.655	0.576	0.556	0.636	0.655	0.257	0.202	0.333
10	0.788	0.634	0.590	0.536	0.788	0.034	0.215	0.010
11	0.798	0.631	0.528	0.502	0.798	-0.013	0.077	0.169
12	0.779	0.700	0.623	0.633	0.779	0.237	0.058	0.227
13	0.730	0.672	0.692	0.701	0.730	0.296	0.307	0.237
14	0.868	0.834	0.788	0.767	0.868	0.323	0.078	0.115
15	0.808	0.750	0.764	0.773	0.808	0.279	0.316	0.238
16	0.697	0.589	0.621	0.592	0.697	0.200	0.310	0.116
17	0.792	0.732	0.671	0.732	0.792	0.281	0.095	0.373
18	0.938	0.880	0.822	0.754	0.938	0.008	-0.031	-0.123
19	0.806	0.819	0.756	0.746	0.806	0.485	0.095	0.096

Table 5.8.4 Log Transformed Vertical Solar Irradiance - 10 minute instantaneous : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.8241	1.1020	-5.9520	-0.4110
10	-3.1581	0.8123	-6.1193	-1.8165
11	-3.0790	1.2240	-6.2660	-0.8780
12	-2.4870	1.2230	-5.9520	-0.6770
13	-2.3410	1.3780	-6.5020	-0.2320
14	-2.2020	1.5350	-6.0320	-0.3660
15	-2.4020	1.5060	-6.5020	-0.2380
16	-2.2980	1.2670	-6.2660	-0.2480
17	-2.0650	1.3410	-6.5020	-0.2560
18	-2.6420	1.1810	-5.9520	-1.0150
19	-2.1120	1.4840	-6.8120	-0.2850
Overall	-2.5115	1.3378	-6.8125	-0.2316

b)

$2/\sqrt{99} = 0.201$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.866	0.758	0.689	0.633	0.866	0.032	0.105	0.037
10	0.788	0.627	0.525	0.471	0.788	0.018	0.069	0.089
11	0.913	0.830	0.755	0.699	0.913	-0.014	-0.004	0.073
12	0.868	0.768	0.707	0.644	0.868	0.062	0.113	-0.008
13	0.895	0.821	0.757	0.689	0.895	0.099	0.028	-0.035
14	0.922	0.863	0.806	0.758	0.922	0.084	-0.003	0.032
15	0.901	0.825	0.783	0.748	0.901	0.069	0.155	0.052
16	0.865	0.766	0.706	0.639	0.865	0.071	0.114	-0.020
17	0.889	0.806	0.740	0.699	0.889	0.073	0.050	0.107
18	0.926	0.847	0.769	0.694	0.926	-0.071	-0.036	-0.025
19	0.895	0.835	0.775	0.728	0.895	0.175	0.008	0.044

Table 5.8.5 Summary information from fitted ARIMA models

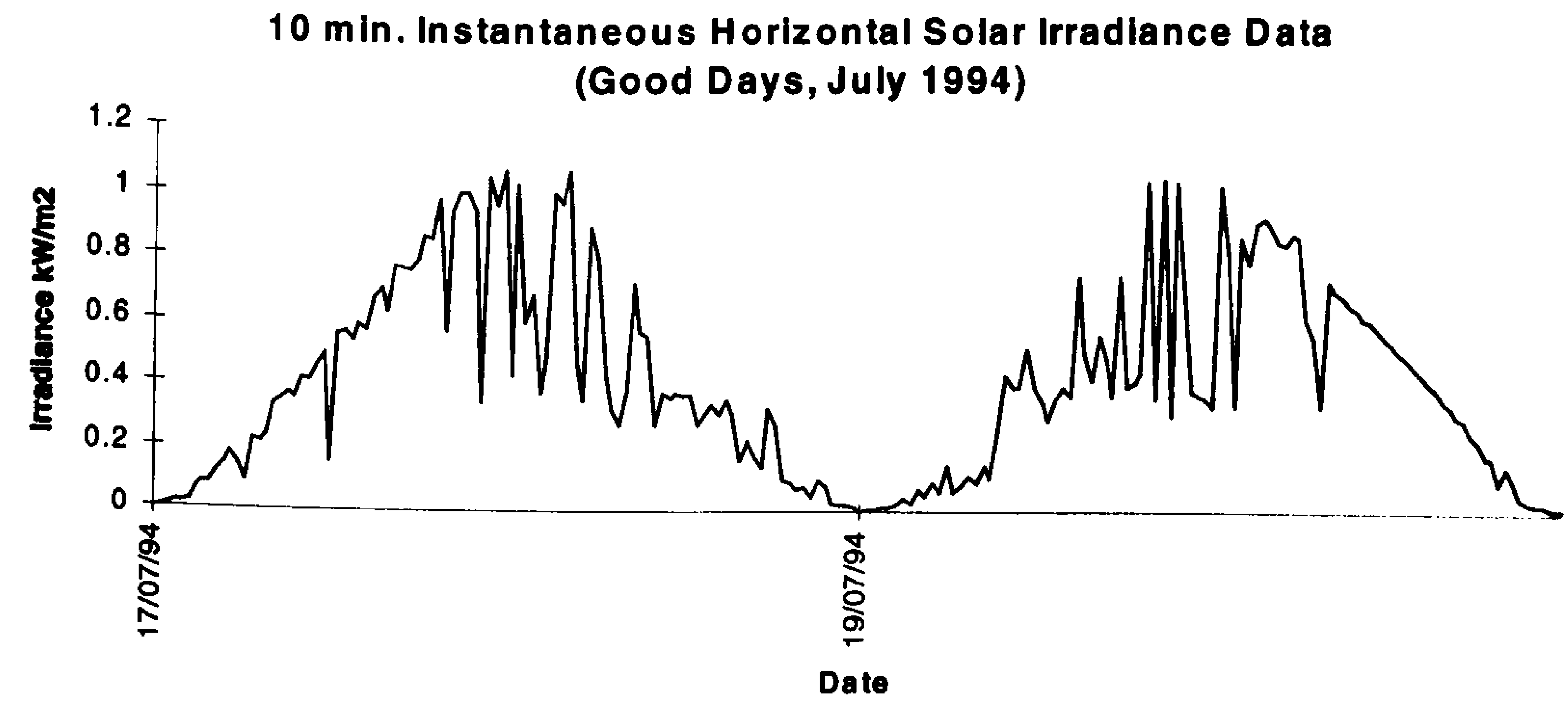
(a)

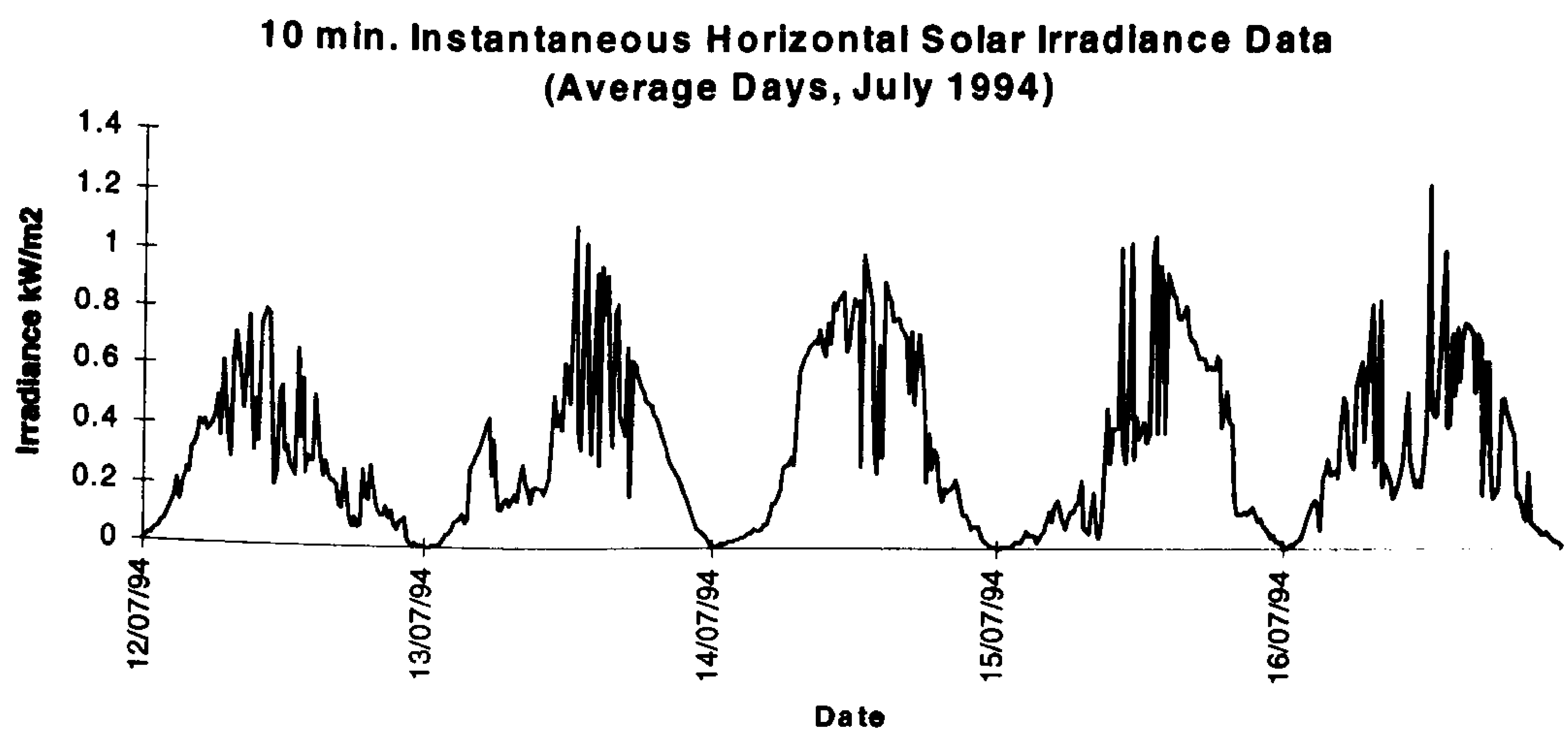
	10 minute instantaneous Horizontal Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(3,1,0)	57		
10	(2,1,0)	55		
11	(1,0,0)	65		
12	(4,1,0)	65		
13	(3,1,0)	60	(1,1,0)	88
14	(1,1,0)	80	(1,1,0)	94
15	(3,1,0)	72	(4,1,0)	89
16	(4,1,0)	51		
17	(4,1,0)	73	(1,1,0)	87
18			(2,1,0)	96
19	(2,1,0)	66	(1,1,0)	90

(b)

	10 minute instantaneous Vertical Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(3,1,0)	54		
10	(2,1,0)	65		
11	(3,1,0)	63		
12	(4,1,0)	70	(1,1,0)	88
13	(3,1,0)	65	(1,1,0)	92
14	(1,1,0)	79	(1,1,0)	95
15	(3,1,0)	74	(4,1,0)	91
16	(4,1,0)	58		
17	(4,1,0)	74		
18			(1,1,0)	97
19	(1,1,0)	75	(1,1,0)	94

Figure 5.8.1 Horizontal Solar Irradiance for 10 minute instantaneous





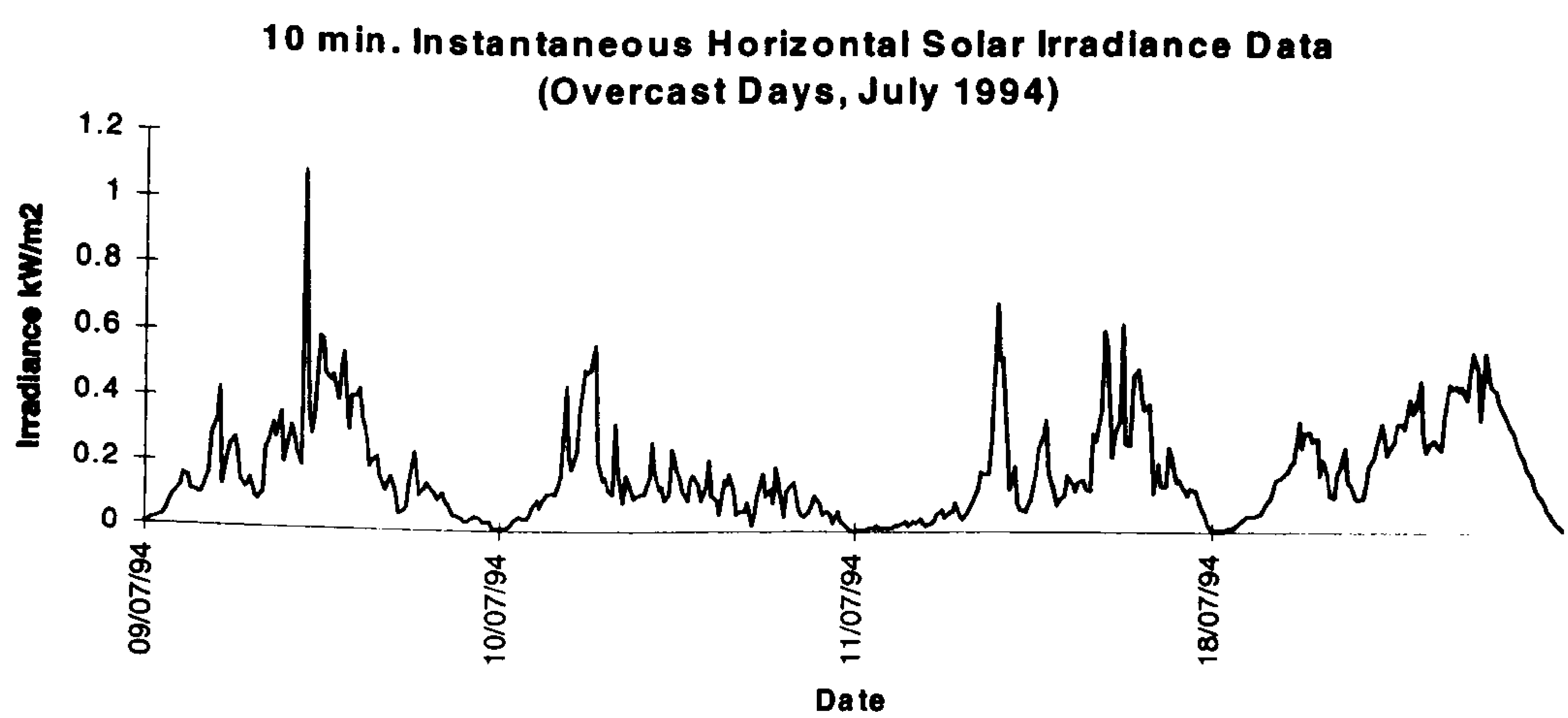
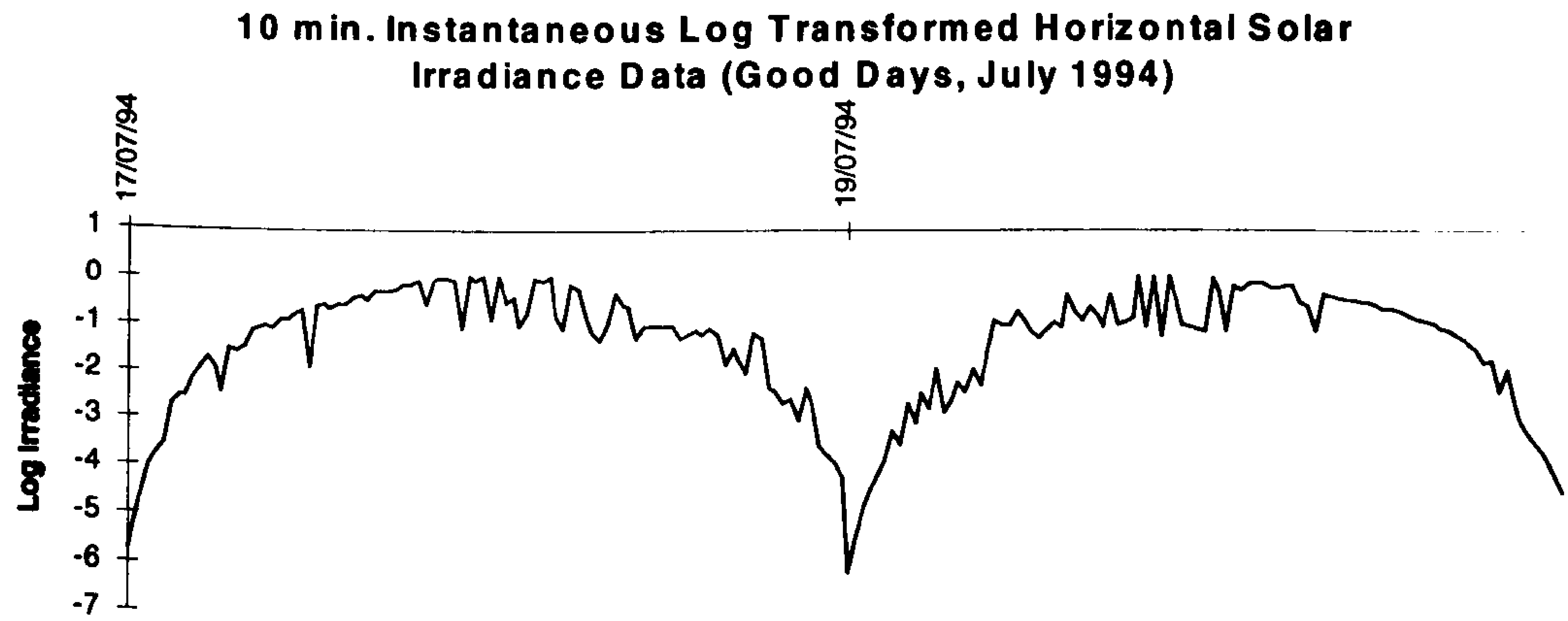
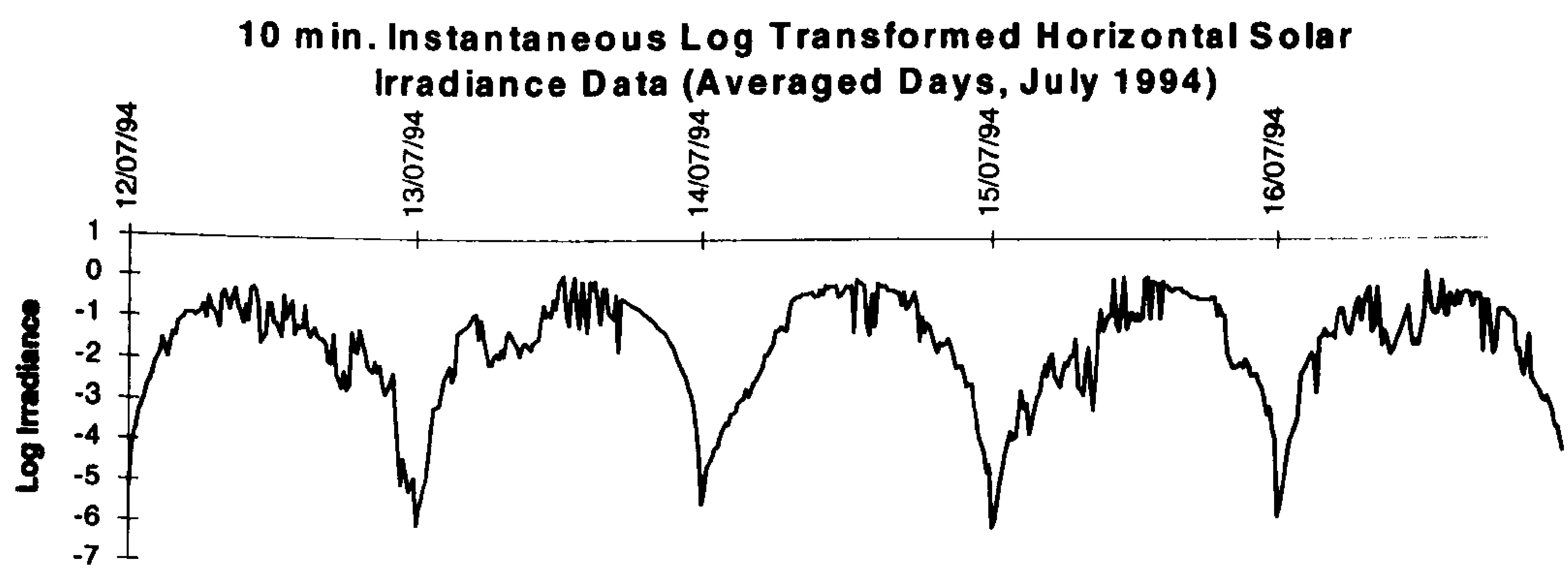


Figure 5.8.2 Log transformed Horizontal Solar Irradiance for 10 minute instantaneous





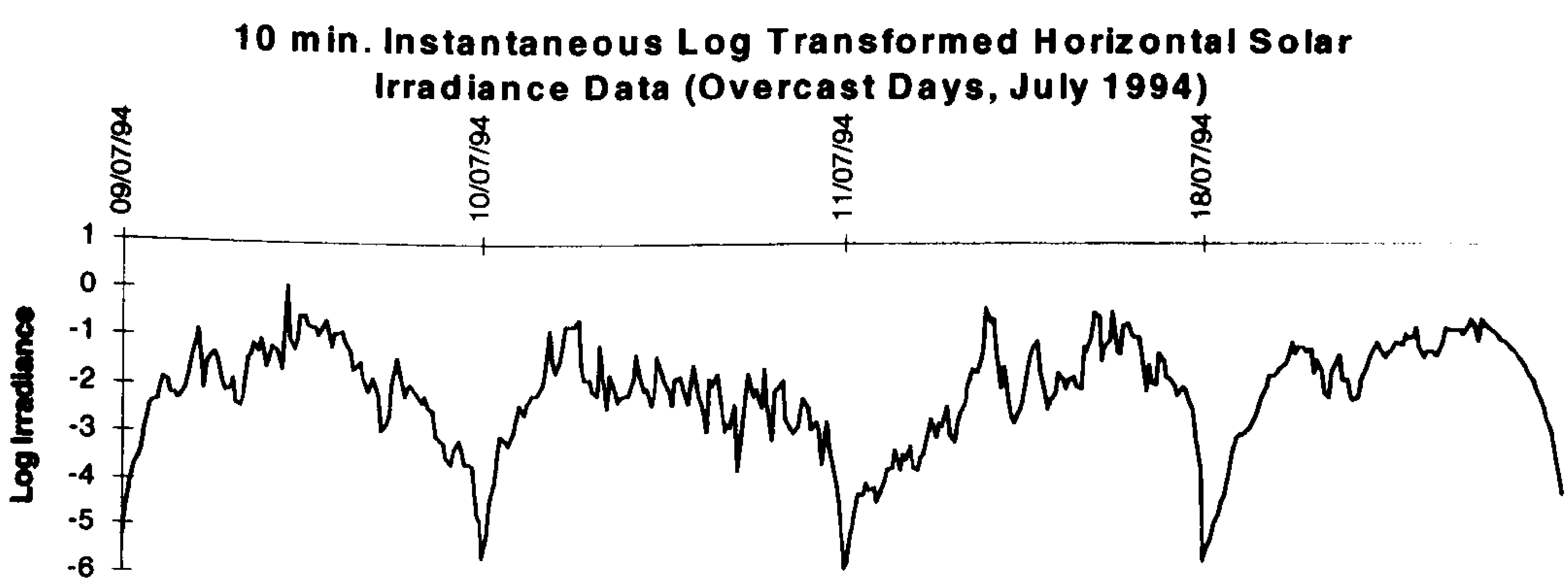
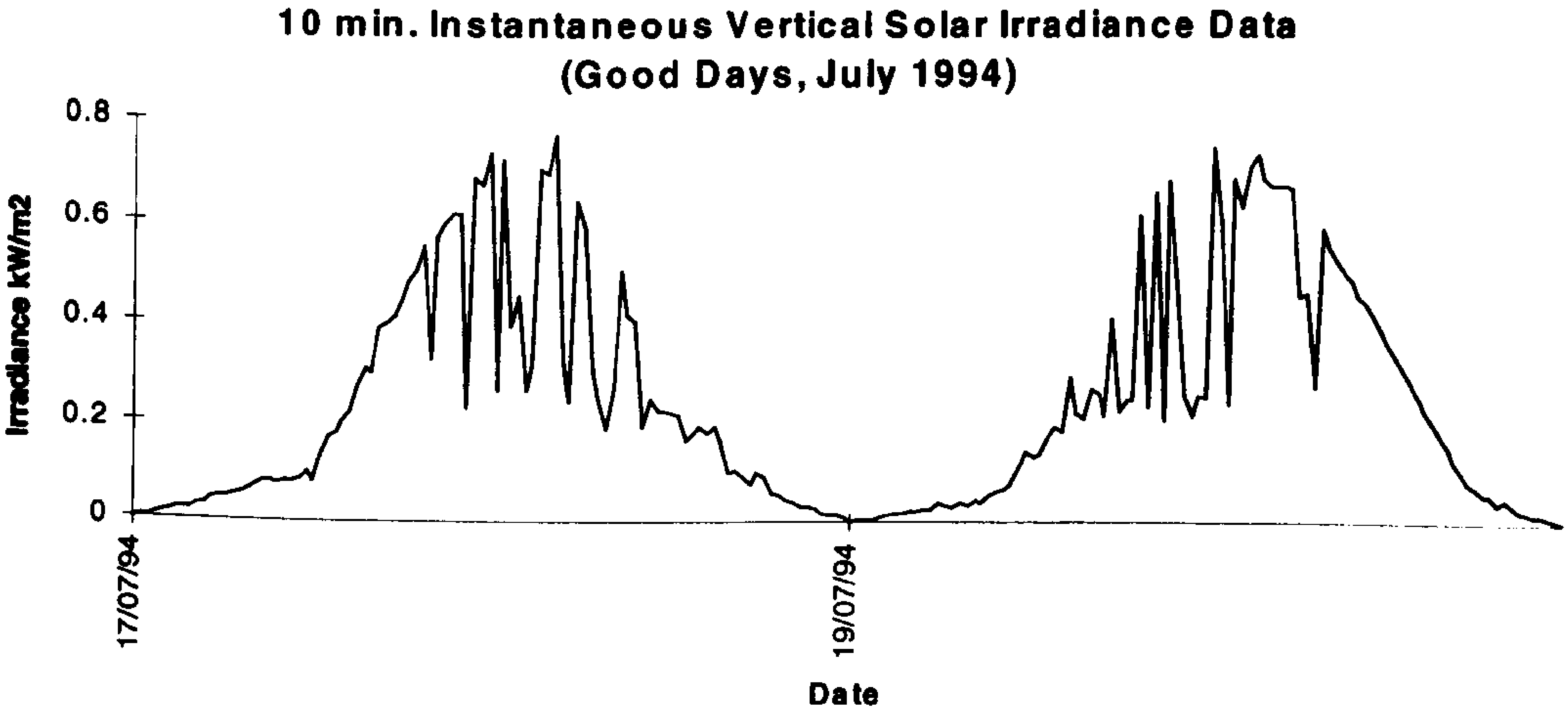
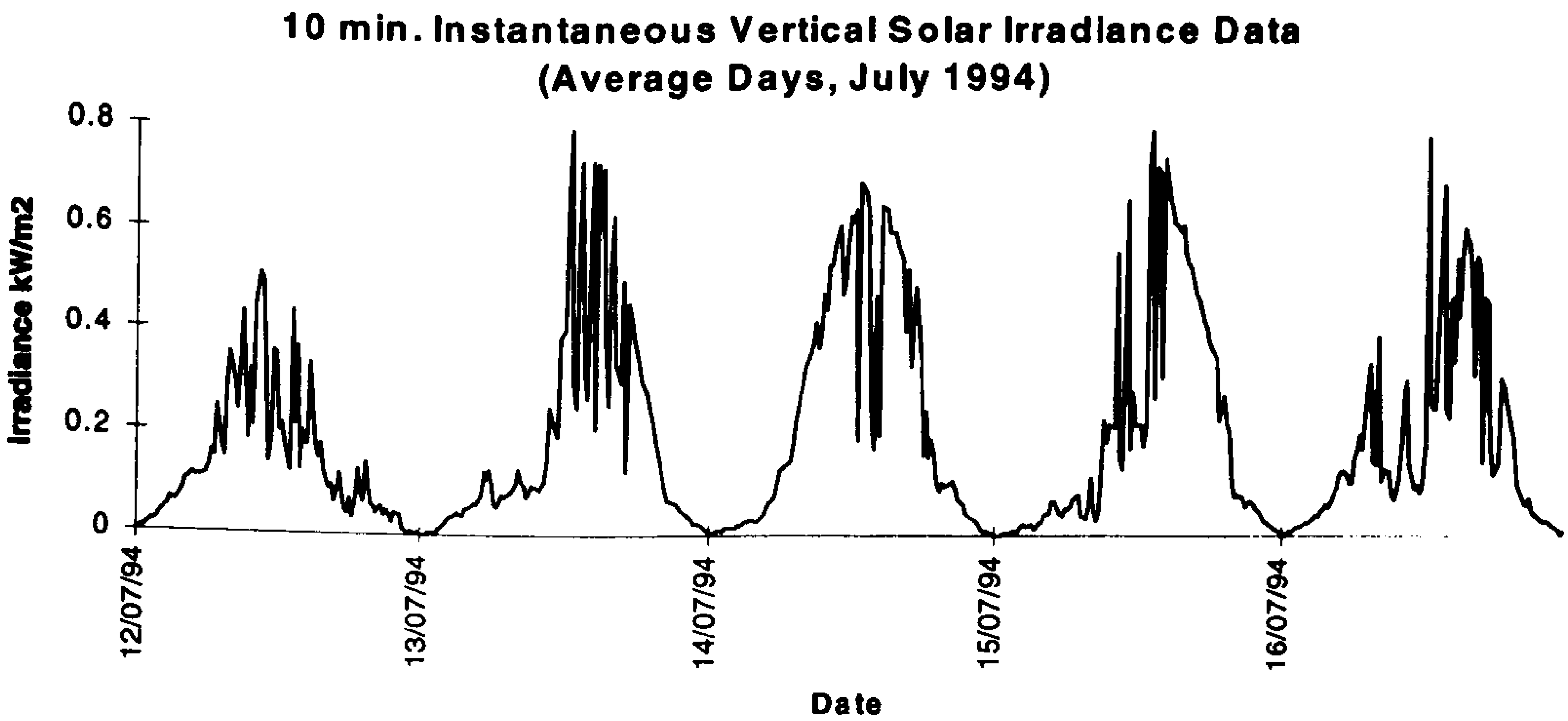


Figure 5.8.3 Vertical Solar Irradiance for 10 minute instantaneous





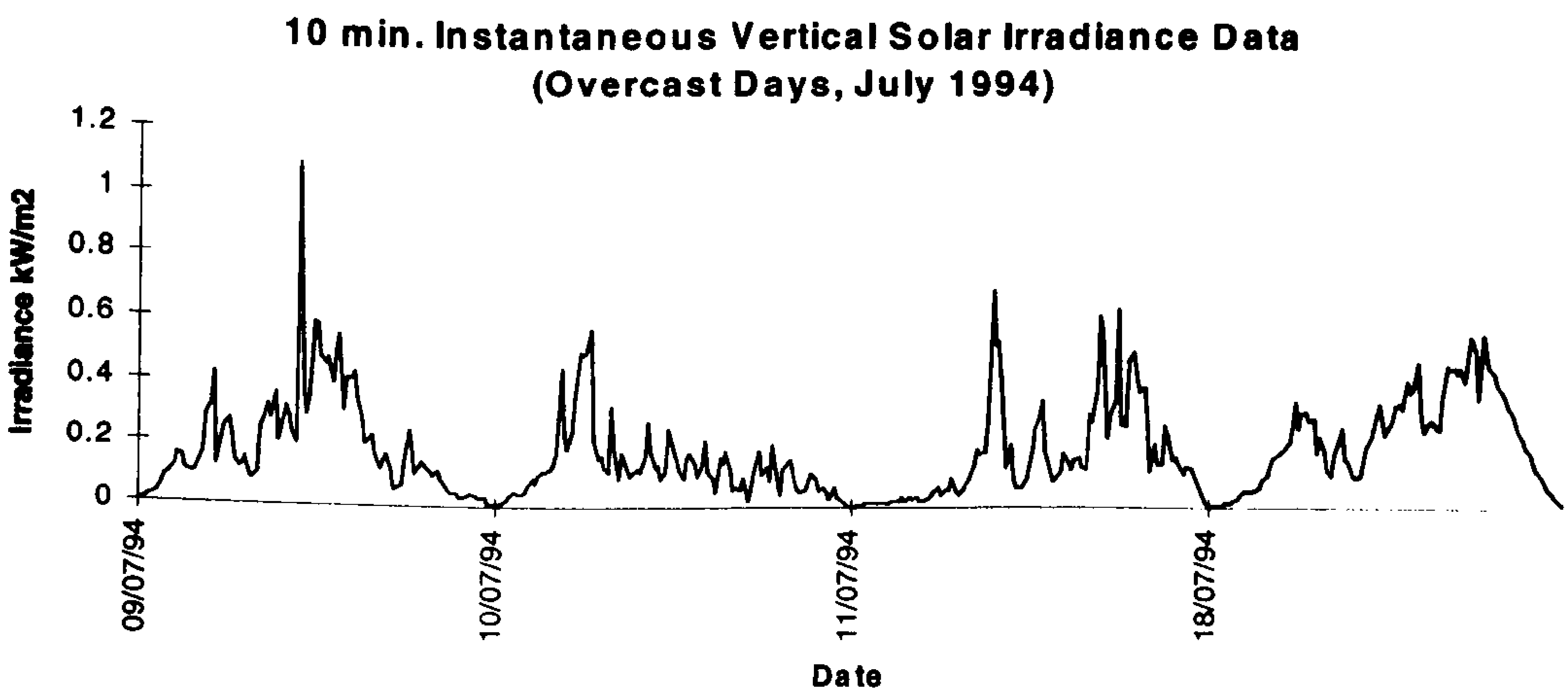
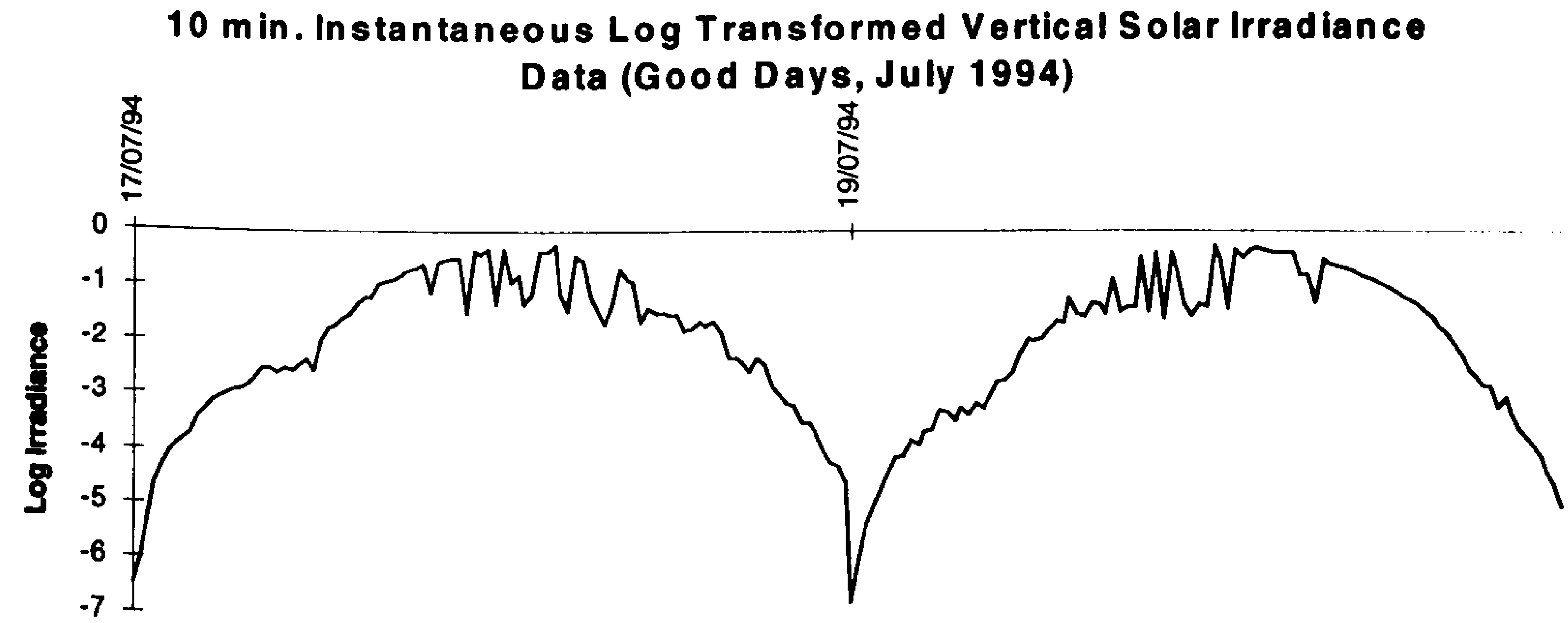
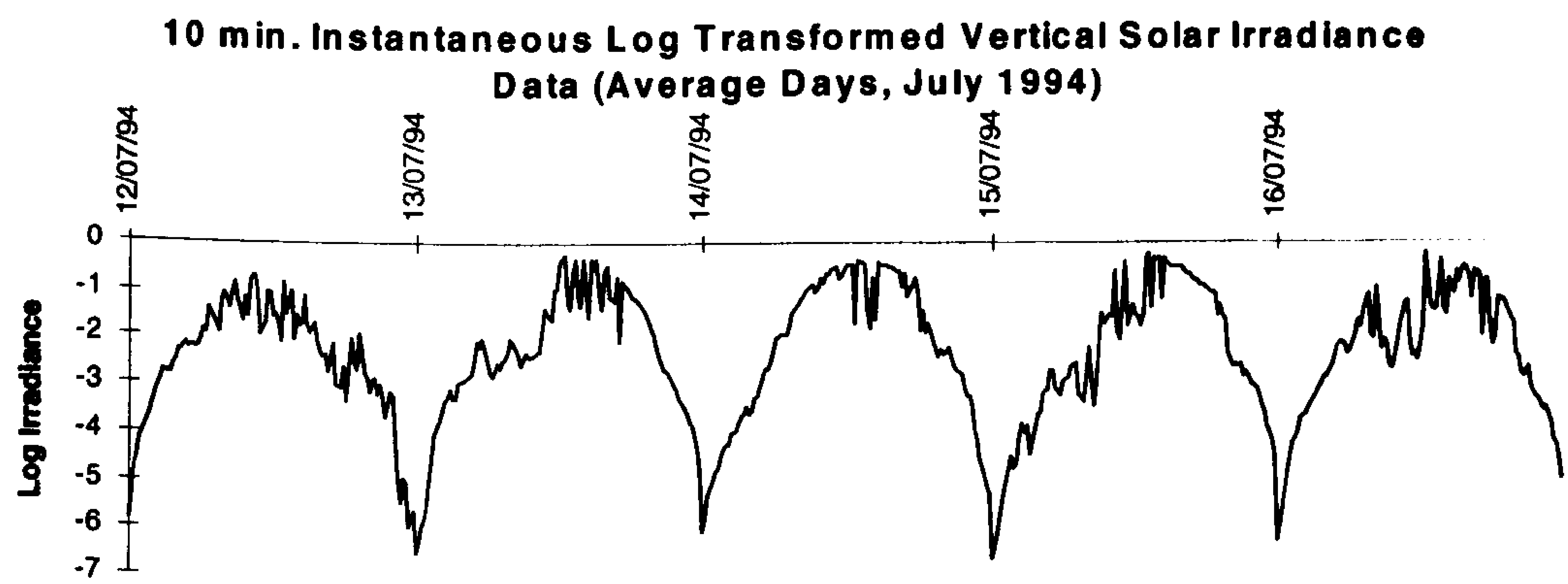
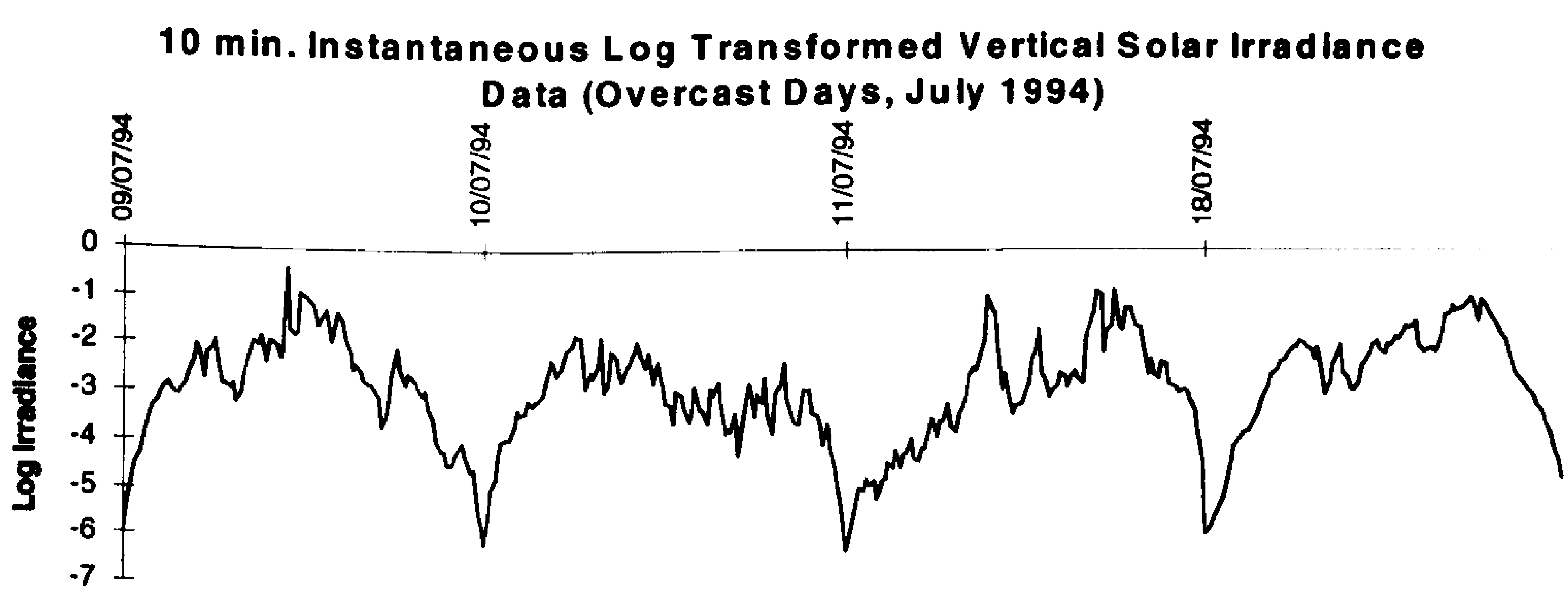


Figure 5.8.4 Log transformed Vertical Solar Irradiance for 10 minute instantaneous







5.9. Five minute averages - July 1994

The 5 minute averaged Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data for the three types of day, Good, Average and Overcast, are displayed in Figure 5.9.1, Figure 5.9.2, Figure 5.9.3 and Figure 5.9.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.9.1(a), Table 5.9.2(a), Table 5.9.3(a) and Table 5.9.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.9.1(b), Table 5.9.2(b), Table 5.9.3(b) and Table 5.9.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.9.5.

Table 5.9.1 Horizontal Solar Irradiance - 5 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.1975	0.1643	0.0063	0.8631
10	0.1318	0.1033	0.0041	0.6150
11	0.1690	0.1576	0.0033	0.6642
12	0.2786	0.2038	0.0050	0.8964
13	0.3253	0.2281	0.0028	0.9524
14	0.3927	0.3151	0.0046	0.9566
15	0.3240	0.3028	0.0023	1.0060
16	0.3275	0.2383	0.0032	1.1420
17	0.4261	0.2950	0.0040	1.0470
18	0.2268	0.1509	0.0037	0.6567
19	0.3879	0.2708	0.0026	1.0216
Overall	0.2898	0.2485	0.0023	1.1420

b)

$2/\sqrt{198} = 0.142$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.885	0.758	0.706	0.688	0.885	-0.117	0.284	0.089
10	0.896	0.797	0.694	0.626	0.896	-0.029	-0.072	0.113
11	0.933	0.864	0.809	0.739	0.933	-0.055	0.070	0.144
12	0.922	0.840	0.775	0.734	0.922	-0.063	0.067	0.120
13	0.890	0.843	0.825	0.805	0.890	0.243	0.208	0.100
14	0.962	0.927	0.912	0.892	0.962	0.033	0.239	-0.054
15	0.920	0.846	0.824	0.801	0.920	-0.005	0.296	0.013
16	0.848	0.751	0.667	0.606	0.848	0.115	0.020	0.053
17	0.924	0.888	0.868	0.822	0.924	0.238	0.164	-0.112
18	0.953	0.914	0.895	0.859	0.953	0.070	0.200	-0.151
19	0.906	0.849	0.844	0.826	0.906	0.158	0.307	0.058

Table 5.9.2 Log Transformed Horizontal Solar Irradiance - 5 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.0321	1.0301	-5.0736	-0.1472
10	-2.3233	0.8506	-5.5066	-0.4861
11	-2.3202	1.1866	-5.7260	-0.4091
12	-1.7221	1.1765	-5.3023	-0.1003
13	-1.5660	1.2256	-5.8853	-0.0488
14	-1.5830	1.4230	-5.3860	-0.0440
15	-1.8008	1.3871	-6.0748	0.0059
16	-1.5611	1.1847	-5.7509	0.1328
17	-1.2916	1.1898	-5.5165	0.0459
18	-1.8861	1.1399	-5.6103	-0.4205
19	-1.4566	1.3193	-5.9677	0.0214
Overall	-1.7766	1.2415	-6.0748	0.1328

b)

$2/\sqrt{198} = 0.142$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.935	0.859	0.793	0.736	0.935	-0.118	0.044	0.016
10	0.897	0.776	0.667	0.589	0.897	-0.147	0.004	0.081
11	0.956	0.905	0.860	0.815	0.956	-0.095	0.044	-0.034
12	0.932	0.867	0.812	0.767	0.932	-0.010	0.044	0.044
13	0.939	0.882	0.832	0.782	0.939	0.003	0.027	-0.021
14	0.961	0.925	0.891	0.858	0.961	0.015	0.019	-0.007
15	0.948	0.890	0.841	0.796	0.948	-0.091	0.066	-0.003
16	0.922	0.849	0.787	0.736	0.922	-0.002	0.029	0.042
17	0.927	0.869	0.819	0.770	0.927	0.075	0.037	-0.011
18	0.951	0.902	0.856	0.808	0.951	-0.026	-0.004	-0.037
19	0.936	0.881	0.840	0.801	0.936	0.037	0.091	0.010

Table 5.9.3 Vertical Solar Irradiance - 5 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.0989	0.1002	0.0028	0.6028
10	0.0551	0.0367	0.0023	0.1862
11	0.0877	0.0948	0.0021	0.4157
12	0.1417	0.1215	0.0019	0.5643
13	0.1848	0.1795	0.0013	0.7287
14	0.2488	0.2261	0.0026	0.6679
15	0.2090	0.2233	0.0014	0.7478
16	0.1772	0.1671	0.0022	0.7904
17	0.2356	0.2061	0.0017	0.7330
18	0.1167	0.0967	0.0025	0.4612
19	0.2465	0.2201	0.0013	0.7299
Overall	0.1638	0.1762	0.0013	0.7904

b)

$2/\sqrt{198} = 0.142$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.870	0.723	0.673	0.668	0.870	-0.143	0.329	0.098
10	0.928	0.824	0.726	0.663	0.928	-0.274	0.045	0.190
11	0.933	0.865	0.811	0.740	0.933	-0.037	0.064	-0.158
12	0.924	0.833	0.761	0.716	0.924	-0.135	0.087	0.126
13	0.907	0.860	0.843	0.830	0.907	0.210	0.213	0.130
14	0.965	0.932	0.915	0.894	0.965	-0.001	0.229	-0.073
15	0.932	0.873	0.853	0.836	0.932	0.034	0.276	0.051
16	0.867	0.783	0.702	0.633	0.867	0.126	-0.004	0.012
17	0.936	0.908	0.893	0.849	0.936	0.257	0.181	-0.167
18	0.960	0.928	0.915	0.882	0.960	0.087	0.225	-0.215
19	0.942	0.904	0.894	0.878	0.942	0.150	0.264	0.038

Table 5.9.4 Log Transformed Vertical Solar Irradiance - 5 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.8105	1.1049	-5.8640	-0.5062
10	-3.1578	0.7989	-6.0662	-1.6809
11	-3.0520	1.2174	-6.1754	-0.8778
12	-2.4738	1.2302	-6.2451	-0.5722
13	-2.3290	1.3462	-6.4253	-0.3165
14	-2.1690	1.5400	-5.9370	-0.4040
15	-2.3860	1.5030	-6.5570	-0.2910
16	-2.2954	1.2385	-6.1284	-0.2352
17	-2.0410	1.3122	-6.3771	-0.3106
18	-2.6269	1.1751	-5.9835	-0.7739
19	-2.1010	1.4600	-6.6150	-0.3150
Overall	-2.4949	1.3280	-6.6151	-0.2352

b)

$2/\sqrt{198} = 0.142$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.942	0.876	0.819	0.771	0.942	-0.105	0.056	0.028
10	0.912	0.808	0.715	0.643	0.912	-0.140	0.016	0.064
11	0.961	0.918	0.879	0.838	0.961	-0.085	0.042	-0.049
12	0.937	0.876	0.826	0.786	0.937	-0.016	0.054	0.064
13	0.956	0.914	0.877	0.841	0.956	0.003	0.039	-0.005
14	0.966	0.935	0.906	0.878	0.966	0.014	0.025	0.001
15	0.958	0.914	0.876	0.842	0.958	-0.062	0.074	0.000
16	0.940	0.880	0.826	0.779	0.940	-0.028	0.017	0.030
17	0.951	0.907	0.869	0.832	0.951	0.032	0.040	0.002
18	0.962	0.922	0.883	0.842	0.962	-0.041	-0.017	-0.041
19	0.954	0.915	0.882	0.852	0.954	0.042	0.064	0.023

Table 5.9.5 Summary information from fitted ARIMA models

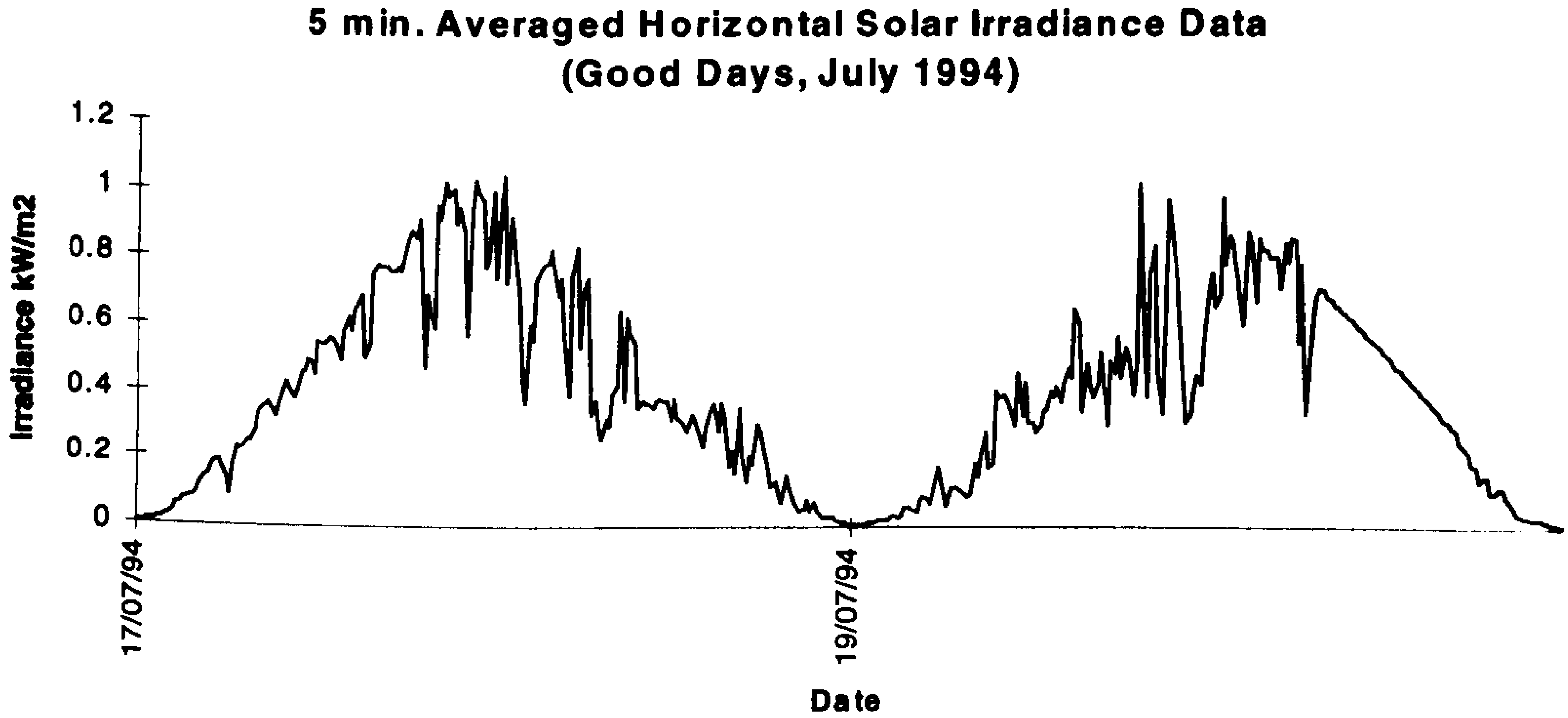
(a)

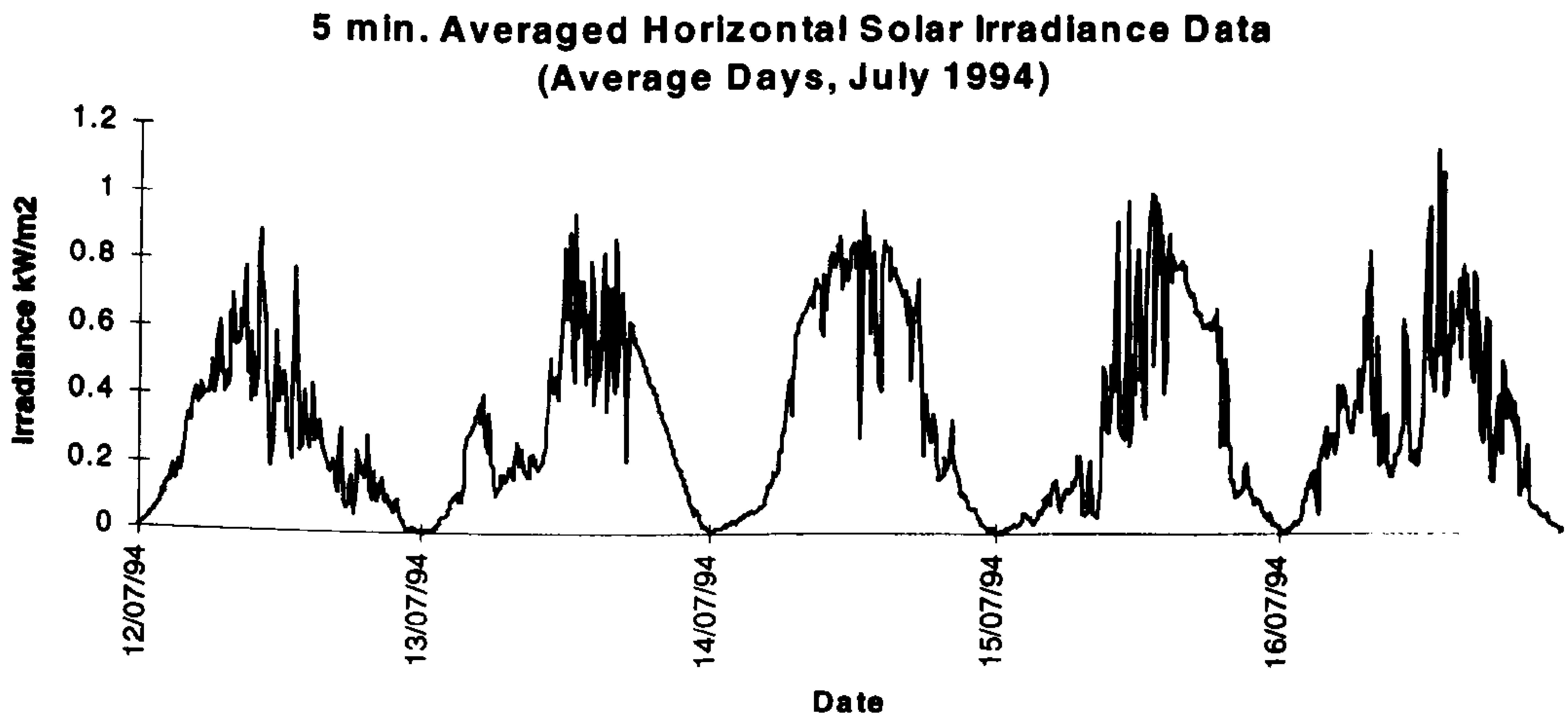
	5 minute averaged Horizontal Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(2,1,0)	81	(2,1,0)	95
10	(3,1,0)	81	(3,1,0)	90
11	(1,0,0)	87	(2,1,0)	96
12	(4,1,0)	87	(2,1,0)	95
13	(3,1,0)	83	(1,1,0)	96
14	(2,1,0)	94	(1,1,0)	98
15	(4,1,0)	87	(4,1,0)	96
16	(1,1,0)	72	(1,1,0)	94
17	(2,1,0)	88	(2,1,0)	95
18	(3,1,0)	93	(3,1,0)	98
19	(2,1,0)	86	(4,1,0)	97

(b)

	5 minute averaged Vertical Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(3,1,0)	79	(2,1,0)	96
10	(2,1,0)	88	(2,1,0)	94
11	(1,0,0)	87	(3,1,0)	96
12	(4,1,0)	87	(3,1,0)	96
13	(4,1,0)	85	(1,1,0)	97
14	(4,1,0)	94	(3,1,0)	98
15	(2,1,0)	88	(2,1,0)	97
16	(2,1,0)	75	(2,1,0)	95
17	(2,1,0)	90	(3,1,0)	97
18	(3,1,0)	94	(3,1,0)	99
19	(2,1,0)	91	(3,1,0)	98

Figure 5.9.1 Horizontal Solar Irradiance for 5 minute averages





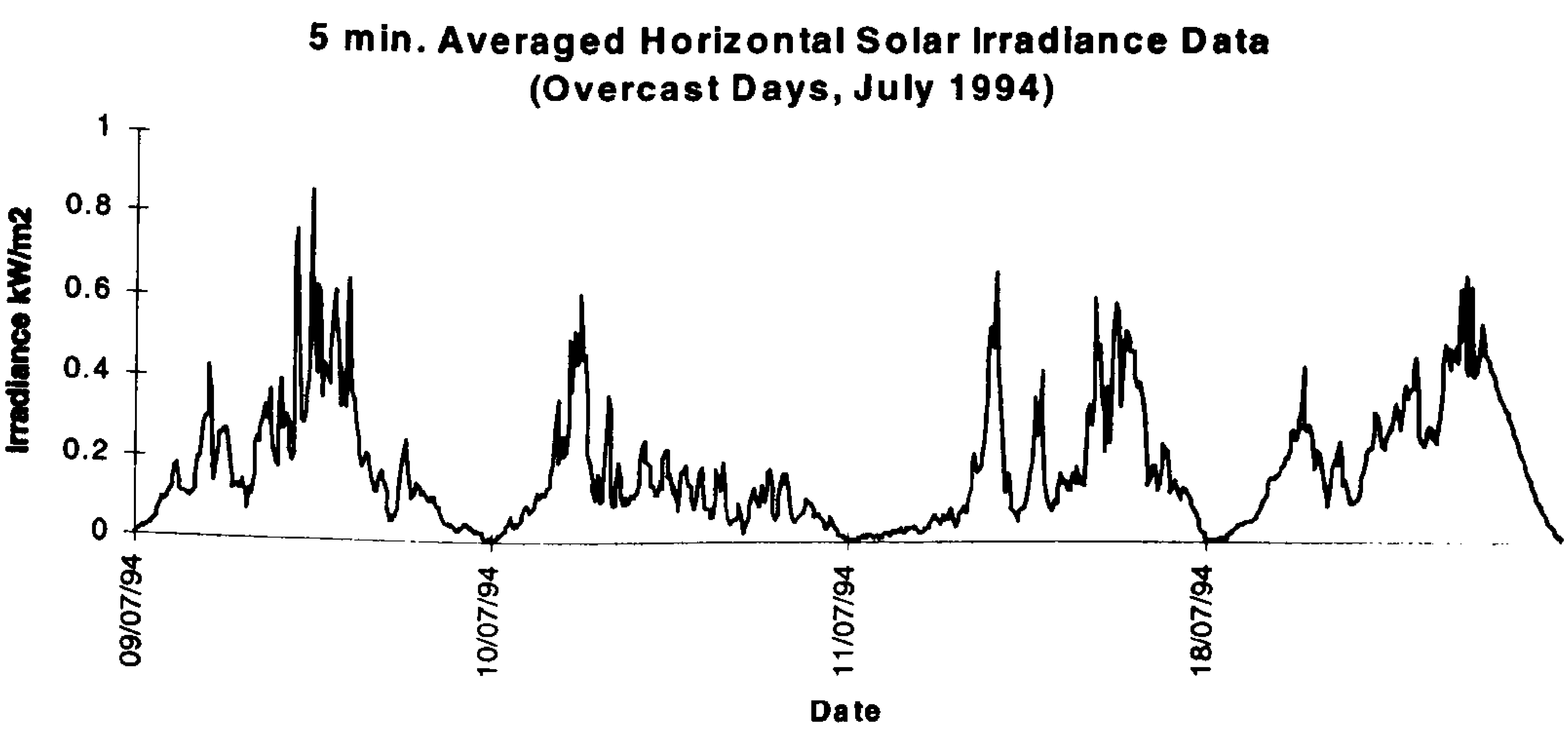
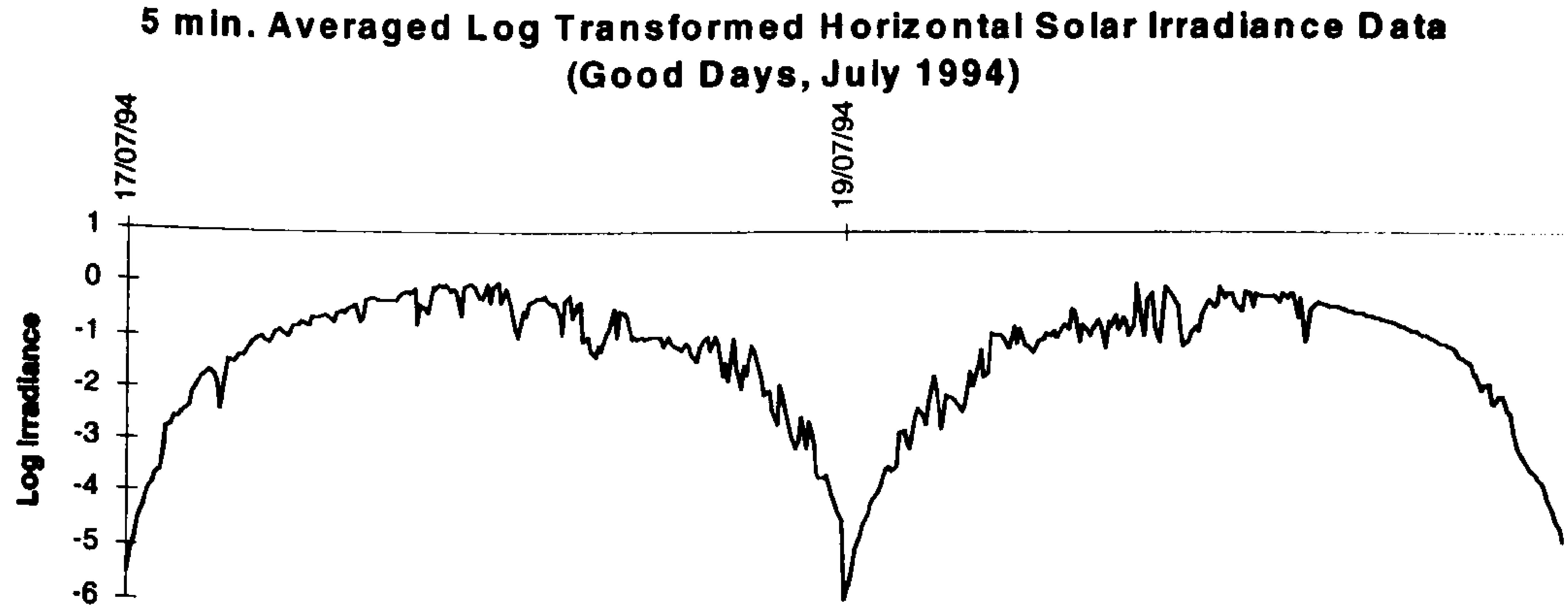
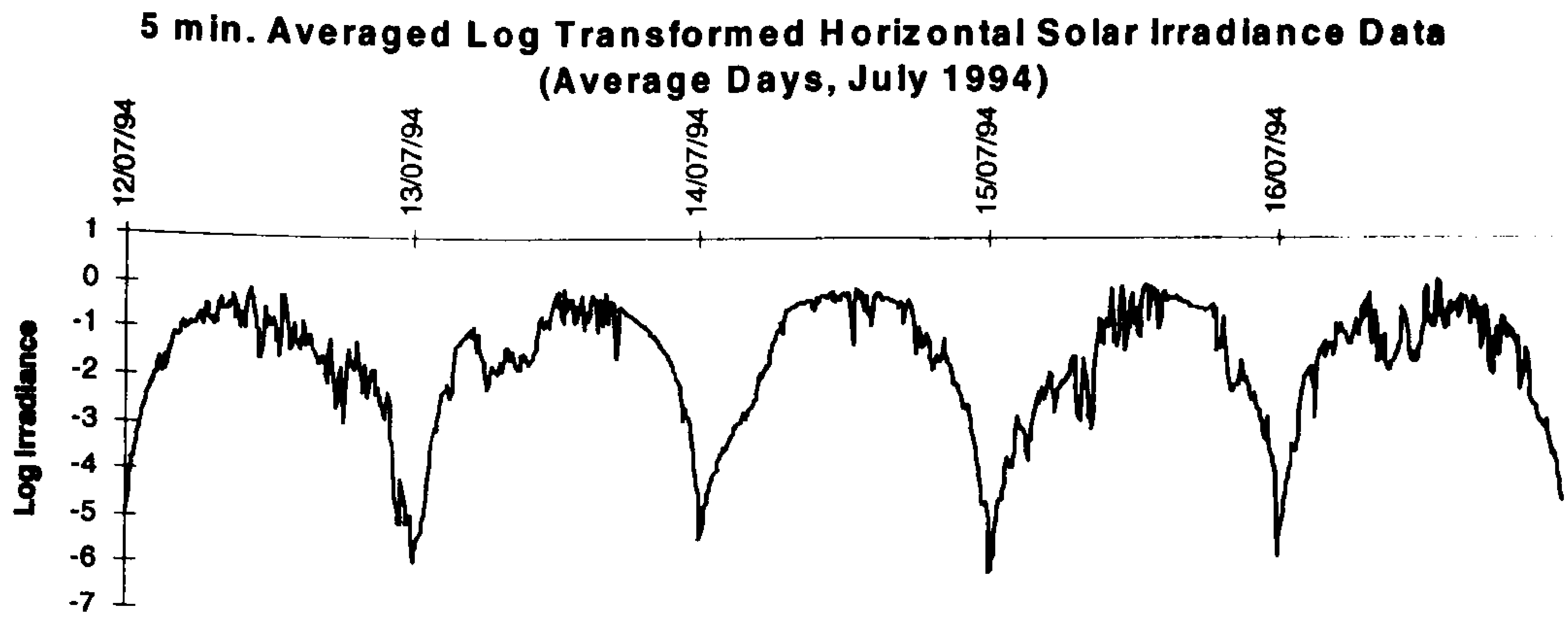


Figure 5.9.2 Log transformed Horizontal Solar Irradiance for 5 minute averages





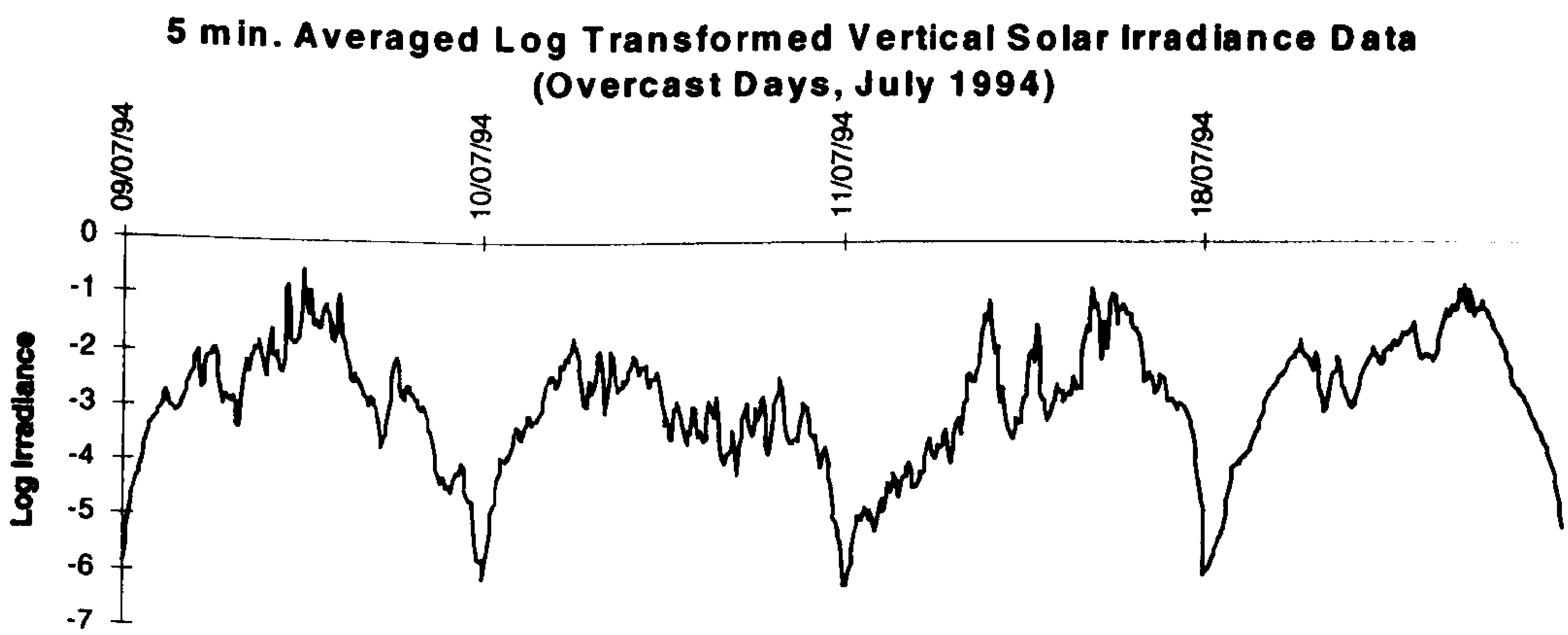
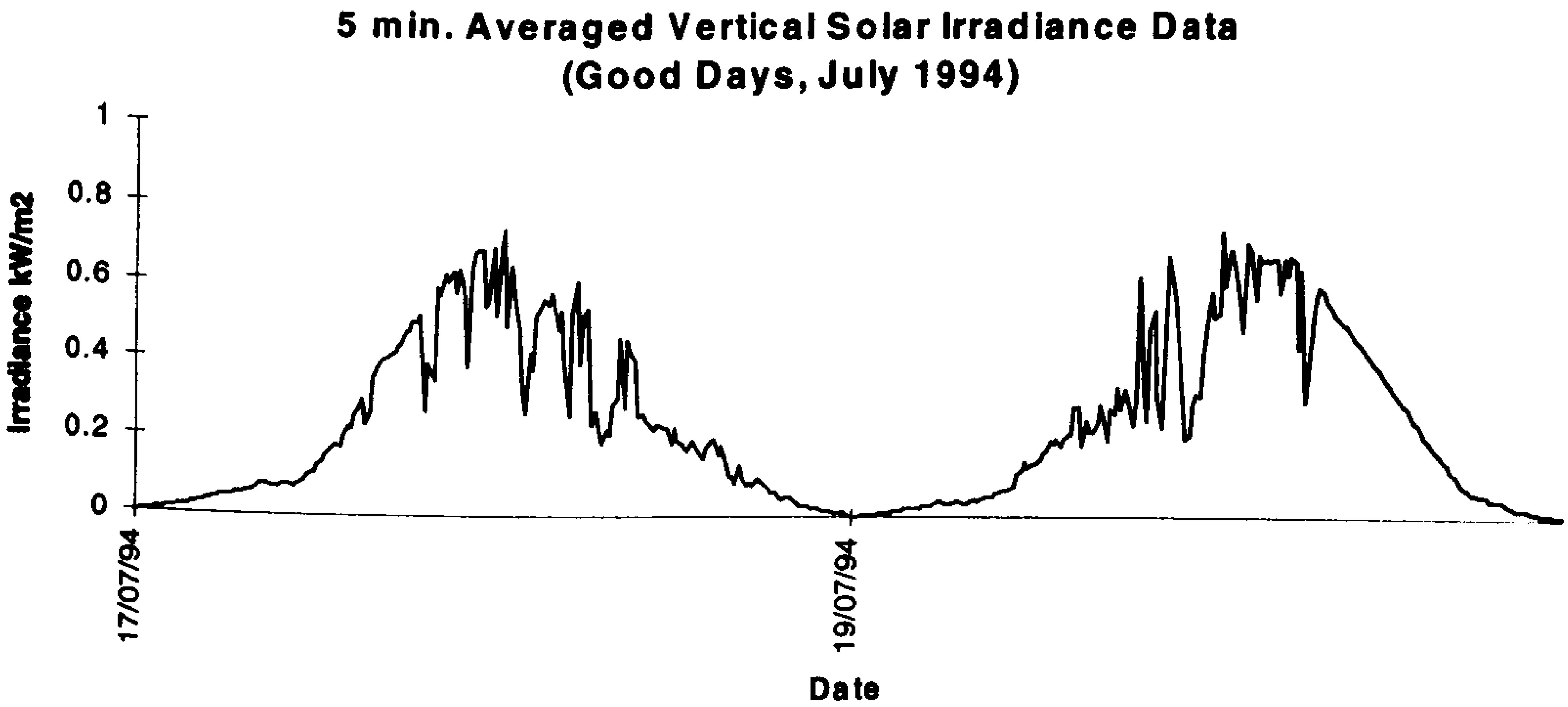
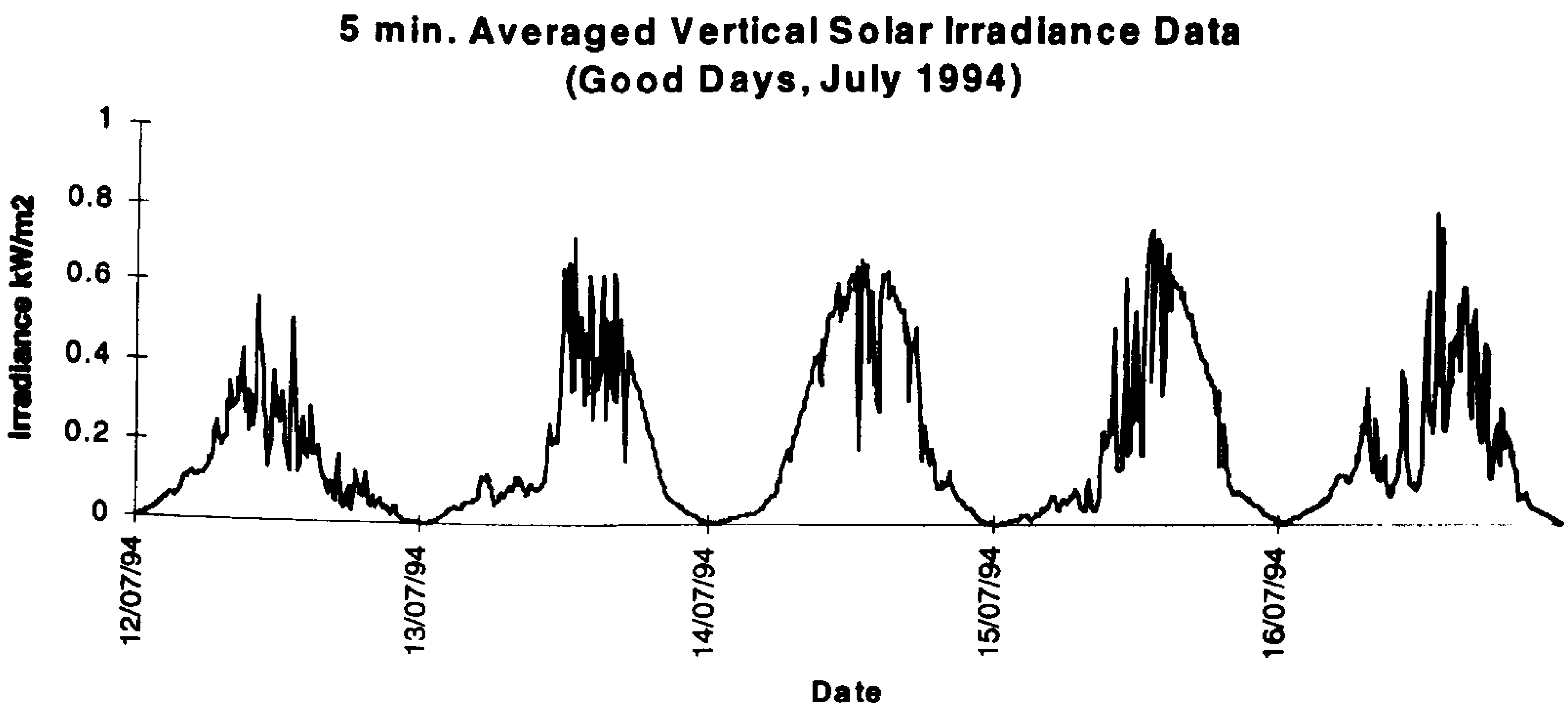


Figure 5.9.3 Vertical Solar Irradiance for 5 minute averages





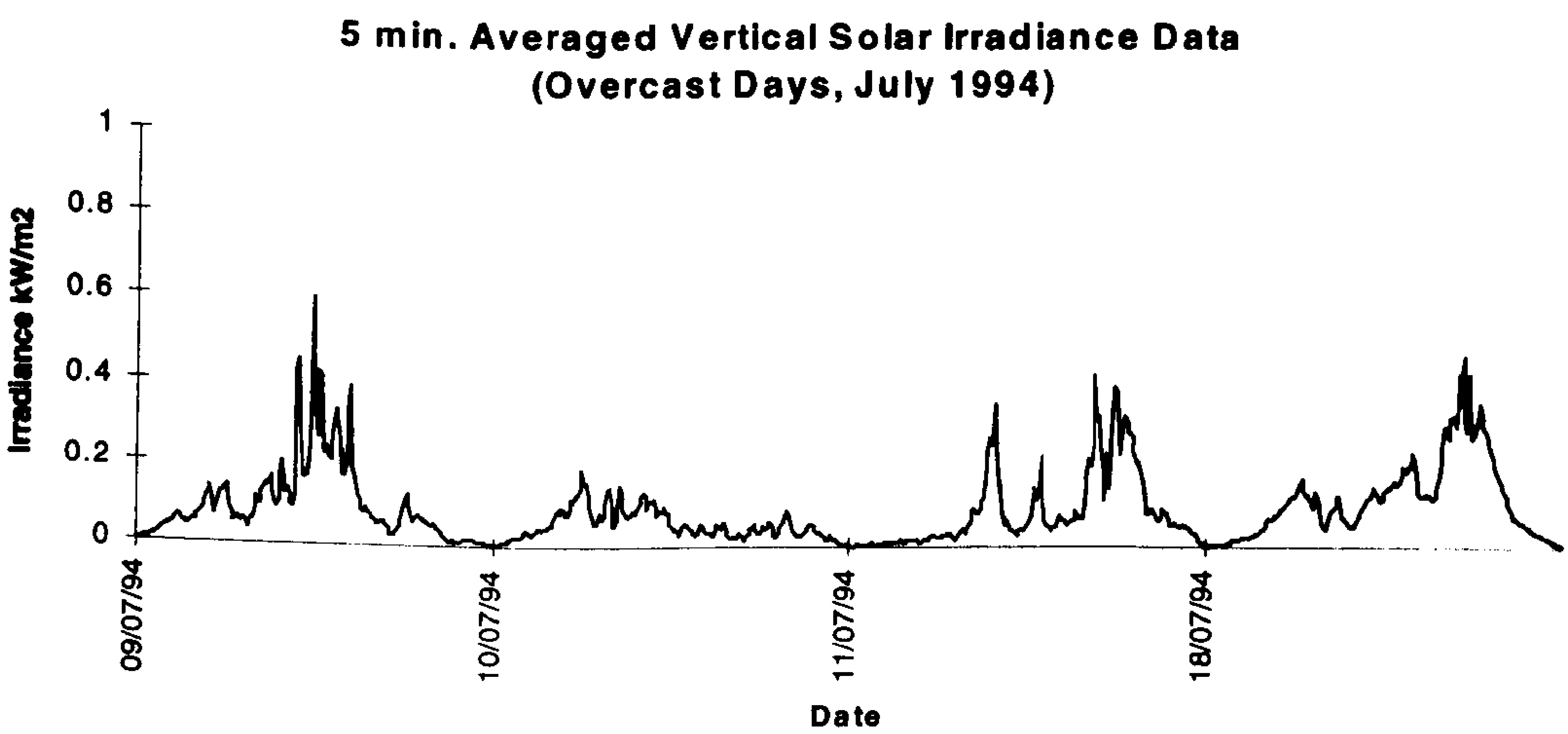
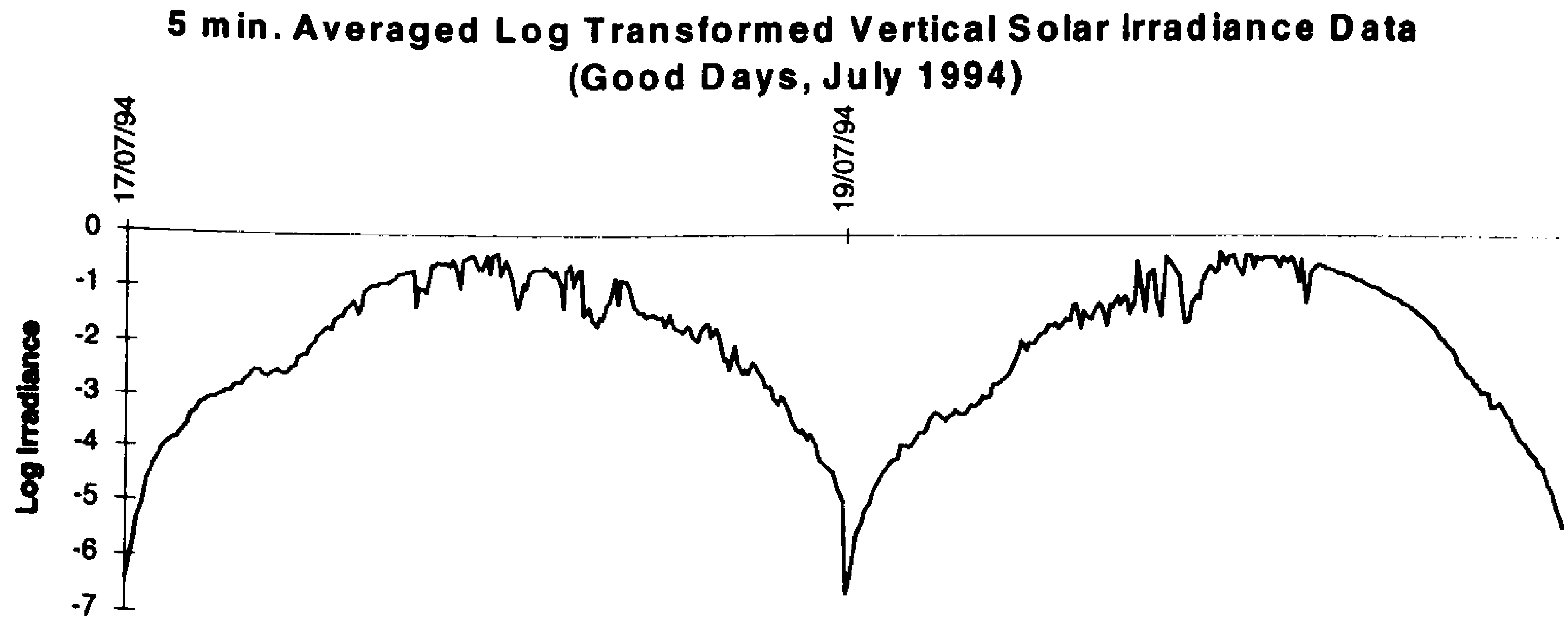
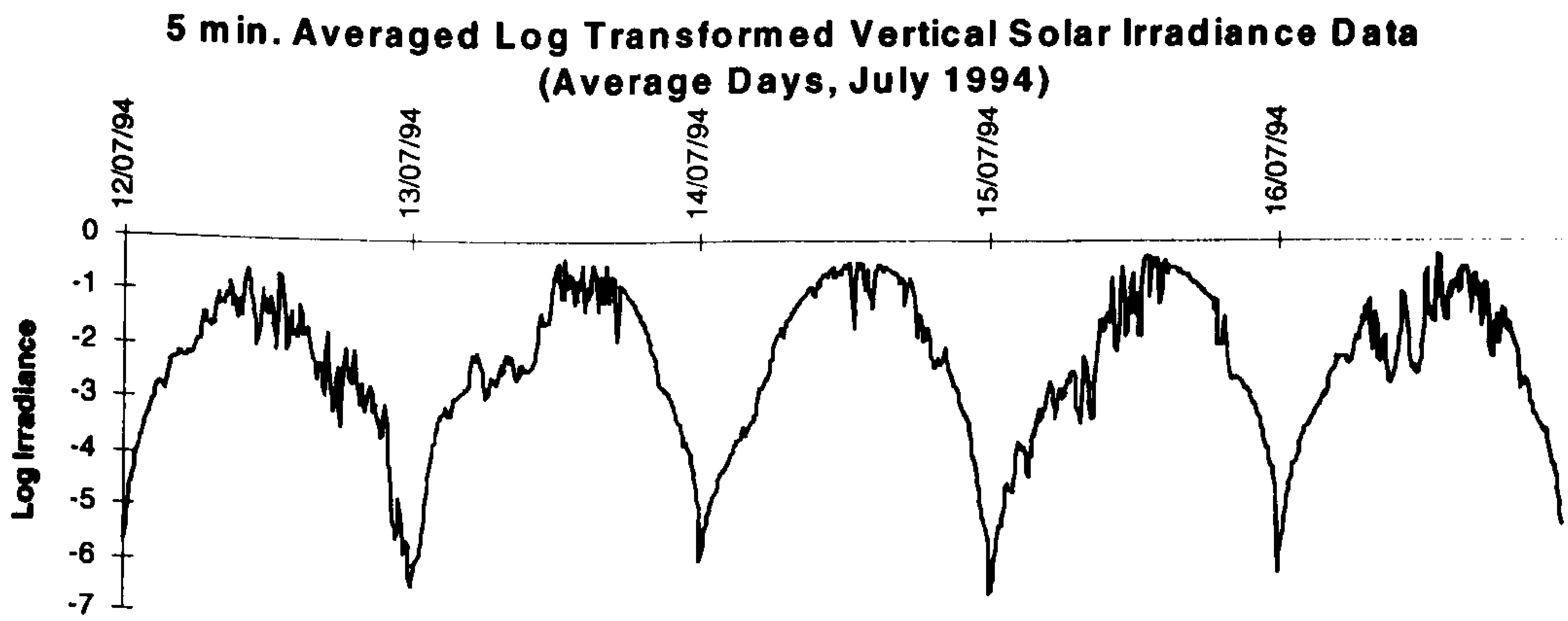
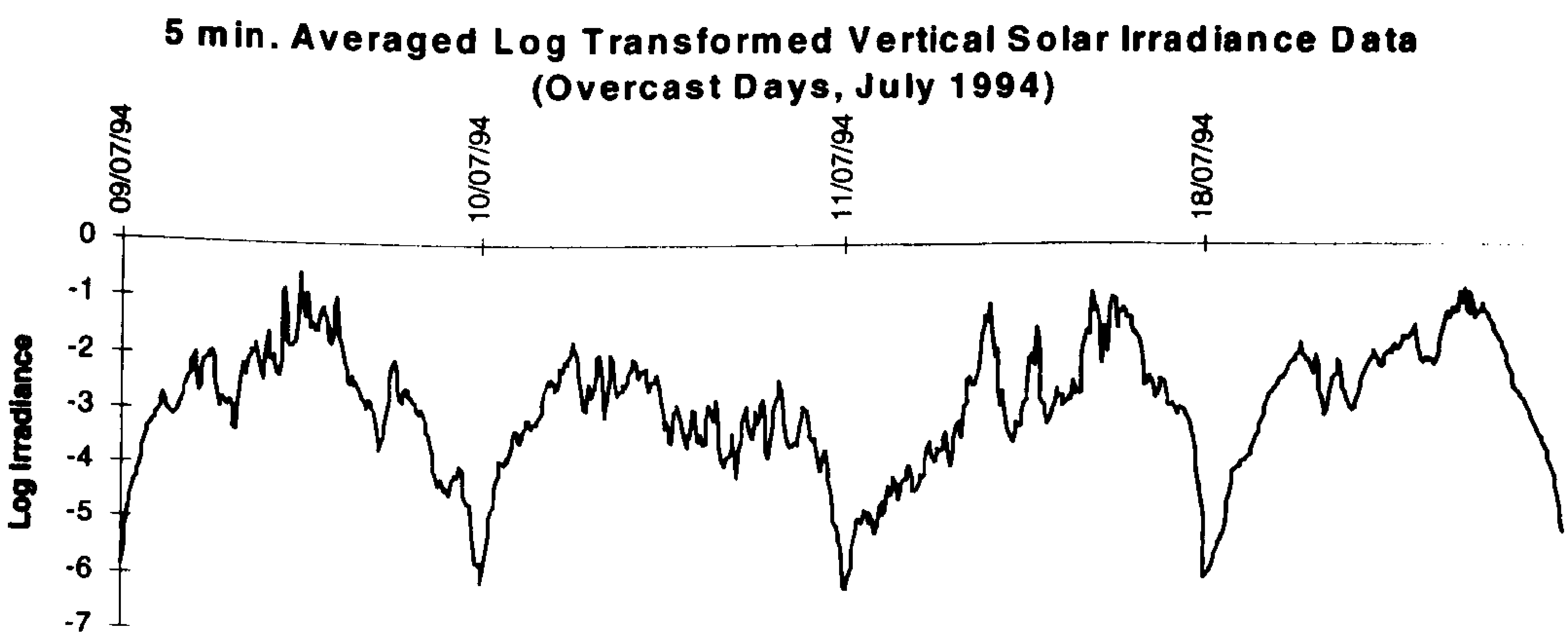


Figure 5.9.4 Log transformed Vertical Solar Irradiance for 5 minute averages







5.10. Ten minute averages - July 1994

The 10 minute averaged Horizontal, Log Transformed Horizontal, Vertical and Log Transformed Vertical Solar Irradiance data for the three types of day, Good, Average and Overcast, are displayed in Figure 5.10.1, Figure 5.10.2, Figure 5.10.3 and Figure 5.10.4 respectively. The corresponding daily descriptive statistics for each set of data are displayed in Table 5.10.1(a), Table 5.10.2(a), Table 5.10.3(a) and Table 5.10.4(a) with the autocorrelation and partial autocorrelation coefficients at the first 4 lags displayed in Table 5.10.1(b), Table 5.10.2(b), Table 5.10.3(b) and Table 5.10.4(b). The most appropriate models for the data and the percentage goodness of fit are displayed in Table 5.10.5.

Table 5.10.1 Horizontal Solar Irradiance - 10 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.1975	0.1606	0.0074	0.7650
10	0.1318	0.1008	0.0047	0.5384
11	0.1690	0.1566	0.0033	0.6408
12	0.2786	0.2022	0.0064	0.8371
13	0.3253	0.2237	0.0030	0.8451
14	0.3927	0.3128	0.0051	0.9009
15	0.3240	0.2978	0.0024	0.9654
16	0.3275	0.2283	0.0038	0.8749
17	0.4261	0.2902	0.0049	1.0149
18	0.2268	0.1504	0.0040	0.6184
19	0.3879	0.2665	0.0031	0.9185
Overall	0.2898	0.2446	0.0024	1.0149

b)

$2/\sqrt{99} = 0.201$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.815	0.728	0.668	0.715	0.815	0.189	0.102	0.358
10	0.836	0.662	0.563	0.453	0.836	-0.125	0.152	-0.128
11	0.880	0.750	0.620	0.524	0.880	-0.108	-0.070	0.068
12	0.859	0.755	0.715	0.689	0.859	0.063	0.206	0.092
13	0.880	0.852	0.799	0.760	0.880	0.343	0.022	0.017
14	0.952	0.908	0.871	0.844	0.952	0.018	0.054	0.090
15	0.894	0.834	0.841	0.839	0.894	0.176	0.355	0.151
16	0.828	0.682	0.647	0.625	0.828	-0.015	0.274	0.065
17	0.924	0.854	0.813	0.794	0.924	0.005	0.159	0.148
18	0.925	0.870	0.806	0.733	0.925	0.098	-0.080	-0.109
19	0.898	0.843	0.801	0.776	0.898	0.186	0.096	0.114

Table 5.10.2 Log Transformed Horizontal Solar Irradiance - 10 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.0250	1.0280	-4.9100	-0.2680
10	-2.3130	0.8400	-5.3517	-0.6192
11	-2.3150	1.1860	-5.7230	-0.1150
12	-1.7160	1.1720	-5.0580	-0.1780
13	-1.5610	1.2250	-5.8160	-0.1680
14	-1.5780	1.4240	-5.2880	-0.1040
15	-1.7920	1.3860	-6.0410	-0.0350
16	-1.5490	1.1800	-5.5620	-0.1340
17	-1.2850	1.1860	-5.3160	0.0015
18	-1.8840	1.1400	-5.5320	-0.4810
19	-1.4500	1.3160	-5.7830	-0.0850
Overall	-1.7698	1.2365	-6.0406	0.0148

b)

$2/\sqrt{99} = 0.201$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.872	0.746	0.665	0.615	0.872	-0.060	0.117	0.084
10	0.801	0.609	0.506	0.437	0.801	-0.090	0.131	0.025
11	0.911	0.821	0.740	0.676	0.911	-0.056	0.009	0.050
12	0.875	0.774	0.703	0.629	0.875	0.033	0.082	-0.036
13	0.888	0.788	0.692	0.603	0.888	-0.006	-0.033	-0.020
14	0.930	0.863	0.799	0.743	0.930	-0.017	-0.016	0.029
15	0.899	0.802	0.753	0.718	0.899	-0.031	0.193	0.060
16	0.866	0.751	0.670	0.591	0.866	0.004	0.074	-0.024
17	0.879	0.778	0.700	0.623	0.879	0.028	0.046	-0.023
18	0.904	0.809	0.721	0.639	0.904	-0.047	-0.015	-0.019
19	0.890	0.804	0.729	0.658	0.890	0.053	0.019	-0.011

Table 5.10.3 Vertical Solar Irradiance - 10 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	0.0989	0.0981	0.0033	0.5381
10	0.0551	0.0362	0.0027	0.1657
11	0.0877	0.0942	0.0021	0.3733
12	0.1417	0.1205	0.0027	0.5188
13	0.1848	0.1767	0.0017	0.6210
14	0.2488	0.2247	0.0029	0.6494
15	0.2090	0.2203	0.0015	0.7092
16	0.1772	0.1610	0.0025	0.6043
17	0.2356	0.2034	0.0019	0.6816
18	0.1167	0.0966	0.0026	0.4391
19	0.2465	0.2182	0.0017	0.6943
Overall	0.1638	0.1738	0.0015	0.7092

b)

$2/\sqrt{99} = 0.201$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.770	0.703	0.629	0.697	0.770	0.272	0.066	0.373
10	0.850	0.690	0.638	0.580	0.850	-0.118	0.292	-0.085
11	0.882	0.749	0.629	0.550	0.882	-0.130	-0.014	0.108
12	0.852	0.737	0.713	0.690	0.852	0.039	0.279	0.059
13	0.892	0.872	0.834	0.815	0.892	0.375	0.077	0.092
14	0.955	0.910	0.875	0.851	0.955	-0.019	0.085	0.113
15	0.911	0.867	0.867	0.855	0.911	0.221	0.312	0.108
16	0.849	0.707	0.697	0.703	0.849	-0.049	0.389	0.079
17	0.942	0.881	0.844	0.824	0.942	-0.067	0.191	0.119
18	0.937	0.890	0.822	0.748	0.937	0.096	-0.178	-0.124
19	0.935	0.890	0.857	0.838	0.935	0.134	0.092	0.128

Table 5.10.4 Log Transformed Vertical Solar Irradiance - 10 minute averages : a) Daily Descriptive Statistics; b) Autocorrelation and Partial Autocorrelation Coefficients at first 4 lags

a)

Date	mean	std. dev.	minimum	maximum
9	-2.8050	1.1050	-5.7260	-0.6200
10	-3.1520	0.7927	-5.9108	-1.7979
11	-3.0470	1.2.80	-6.1750	-0.9850
12	-2.4670	1.2250	-5.9150	-0.6560
13	-2.3240	0.3480	-6.3890	-0.4760
14	-2.1650	1.5420	-5.8460	-0.4320
15	-2.3780	1.5040	-6.5290	-0.3440
16	-2.2860	1.2400	-5.9870	-0.5040
17	-2.0340	1.3090	-6.2310	-0.3830
18	-2.6250	1.1760	-5.9370	-0.8230
19	-2.0970	1.4610	-6.3710	-0.3650
Overall	-2.4895	1.3255	-6.5293	-0.3436

b)

$2/\sqrt{99} = 0.201$	Autocorrelation Coefficient				Partial Autocorrelation Coefficient			
Date	Lag 1	Lag 2	Lag 3	Lag 4	Lag 1	Lag 2	Lag 3	Lag 4
9	0.884	0.777	0.700	0.647	0.884	-0.020	0.076	0.077
10	0.823	0.656	0.556	0.492	0.823	-0.067	0.111	0.049
11	0.924	0.843	0.767	0.706	0.924	-0.066	-0.018	0.067
12	0.886	0.784	0.732	0.665	0.886	0.040	0.096	-0.032
13	0.918	0.846	0.773	0.703	0.918	0.019	-0.040	-0.023
14	0.939	0.882	0.826	0.775	0.939	-0.003	-0.013	0.008
15	0.921	0.848	0.803	0.767	0.921	-0.003	0.151	0.041
16	0.891	0.791	0.720	0.657	0.891	-0.015	0.091	0.005
17	0.916	0.840	0.779	0.726	0.916	0.013	0.045	0.033
18	0.924	0.844	0.765	0.689	0.924	-0.070	-0.036	-0.018
19	0.920	0.855	0.800	0.750	0.920	0.052	0.040	0.016

Table 5.10.5 Summary information from fitted ARIMA models

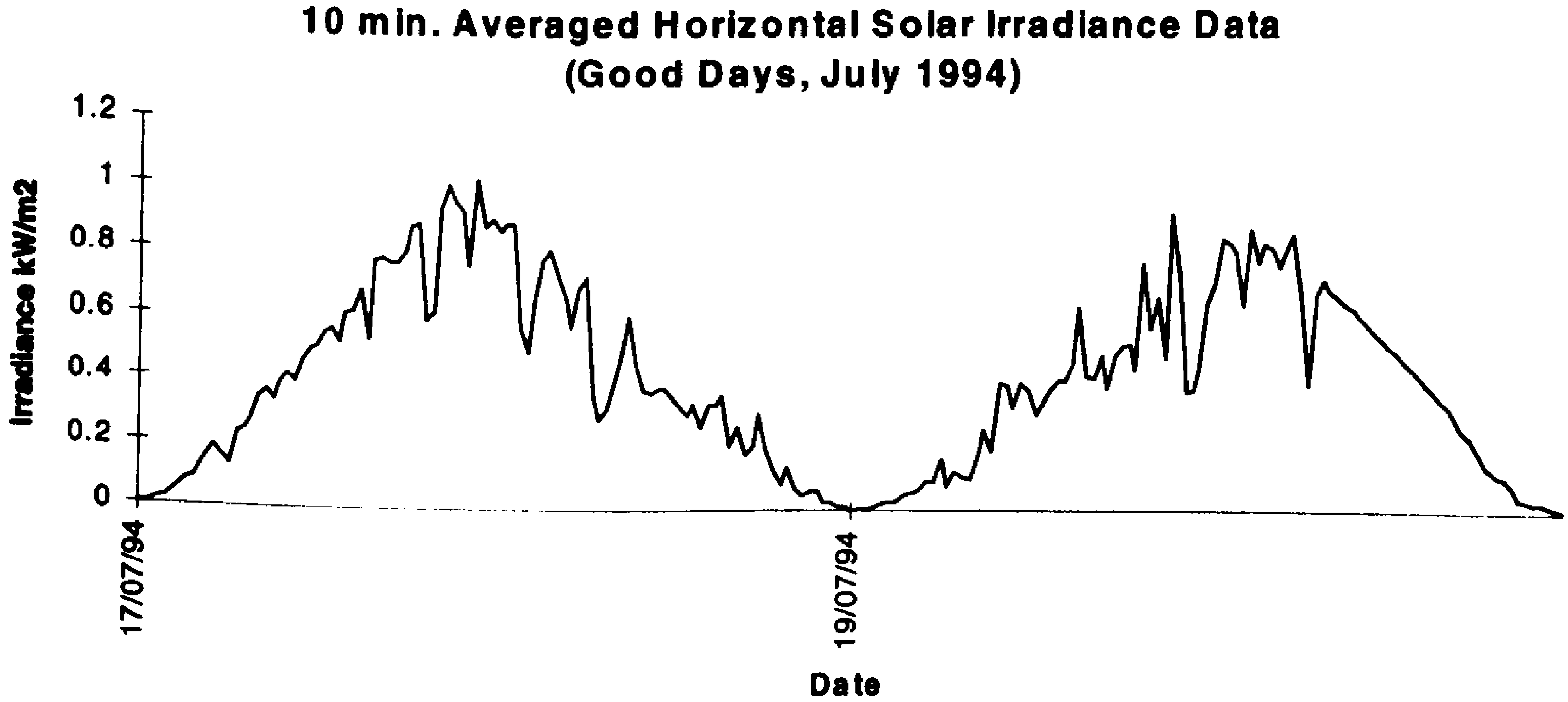
(a)

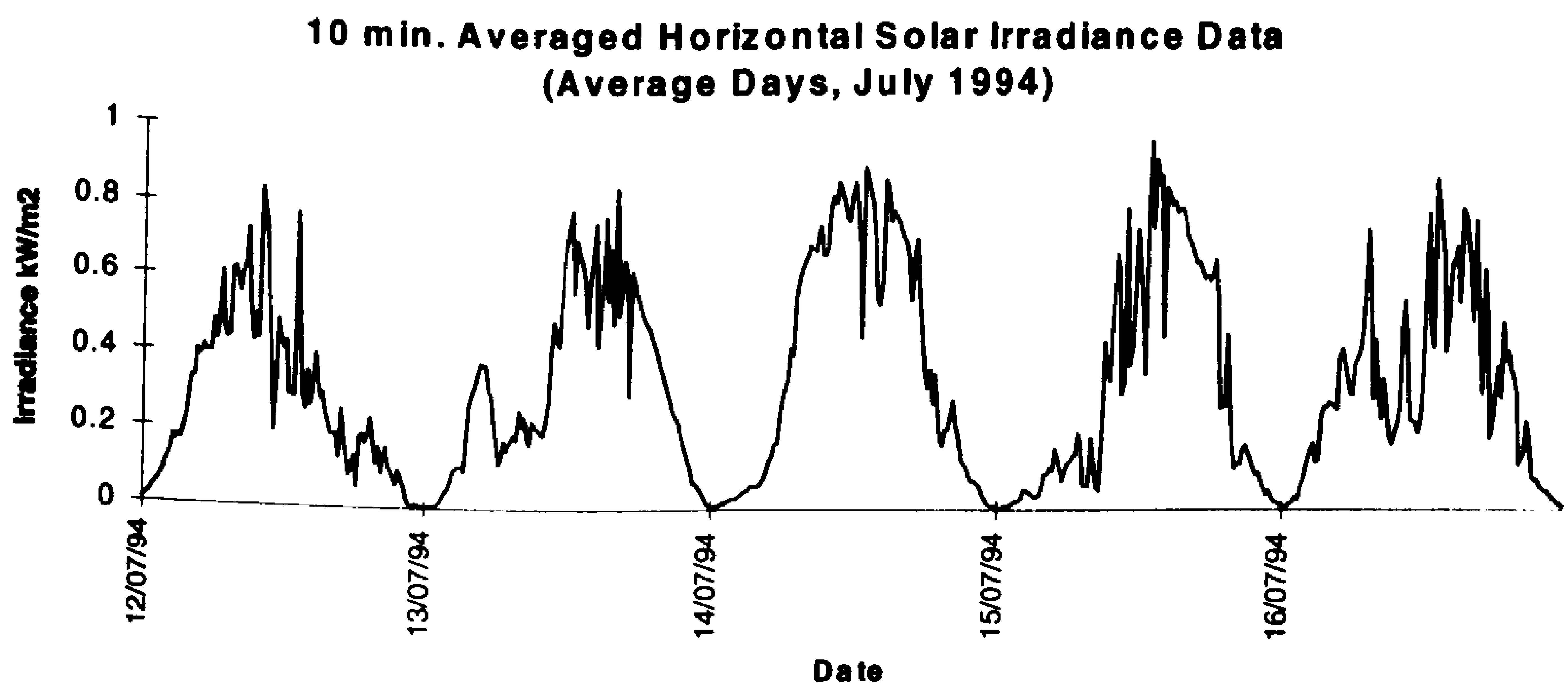
	10 minute averaged Horizontal Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(3,1,0)	74	(2,1,0)	89
10	(2,1,0)	71	(2,1,0)	82
11	(1,0,0)	78	(2,1,0)	92
12	(4,1,0)	79	(2,1,0)	90
13	(1,1,0)	84	(2,1,0)	95
14	(1,1,0)	93	(2,1,0)	98
15	(3,1,0)	85	(2,1,0)	93
16	(2,1,0)	73	(2,1,0)	91
17	(3,1,0)	90	(4,1,0)	95
18	(1,1,0)	89	(1,1,0)	97
19	(3,1,0)	86	(3,1,0)	96

(b)

	10 minute averaged Vertical Solar Irradiance			
	Original Data		Log Transformed Data	
Date	Model	% Fit	Model	% Fit
9	(3,1,0)	68	(4,1,0)	91
10	(2,1,0)	78	(2,1,0)	86
11	(1,0,0)	78	(1,1,0)	93
12	(4,1,0)	78	(2,1,0)	91
13	(1,1,0)	84	(2,1,0)	96
14	(1,1,0)	93	(2,1,0)	98
15	(4,1,0)	88	(2,1,0)	94
16	(2,1,0)	78	(2,1,0)	93
17	(2,1,0)	91	(1,1,0)	97
18	(1,0,0)	90	(1,1,0)	97
19	(3,1,0)	90	(1,1,0)	97

Figure 5.10.1 Horizontal Solar Irradiance for 10 minute averages





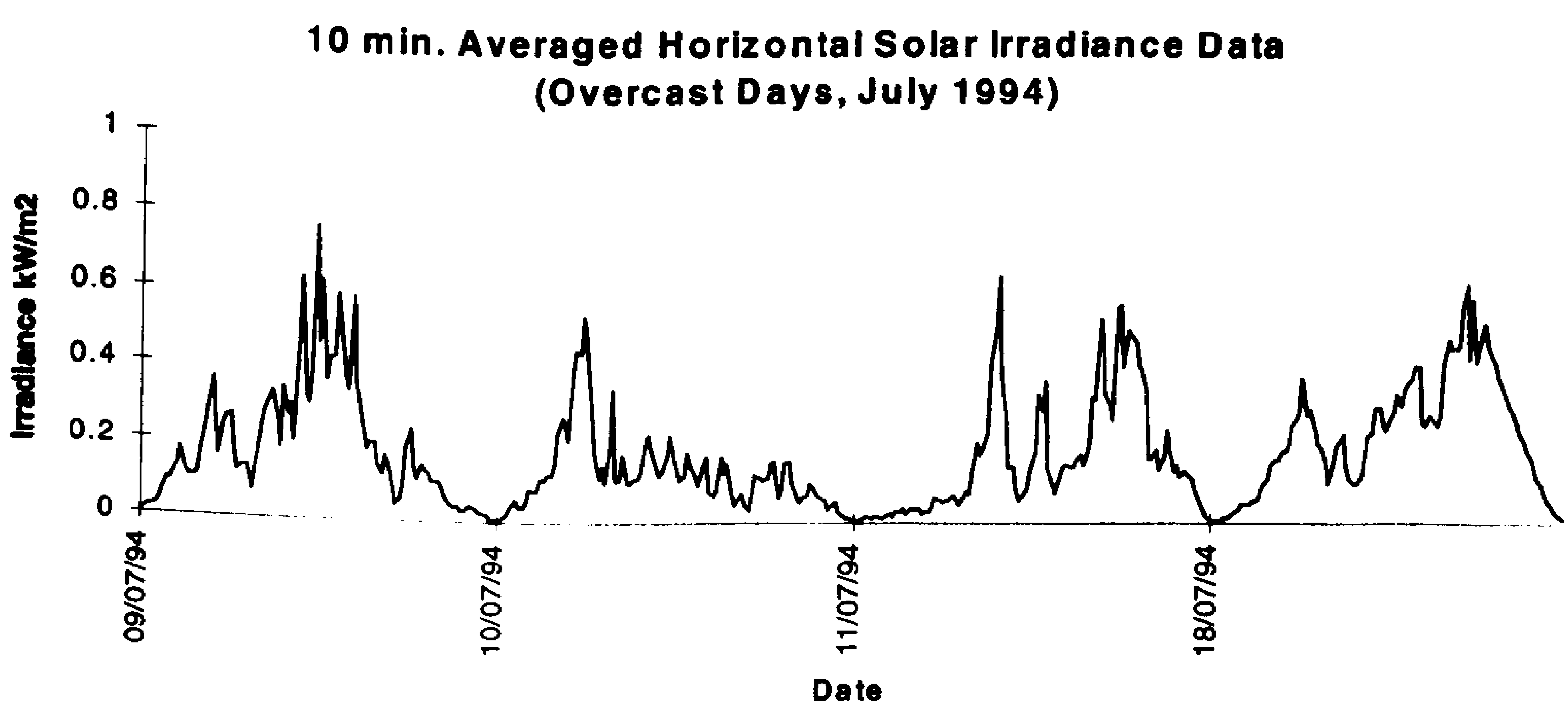
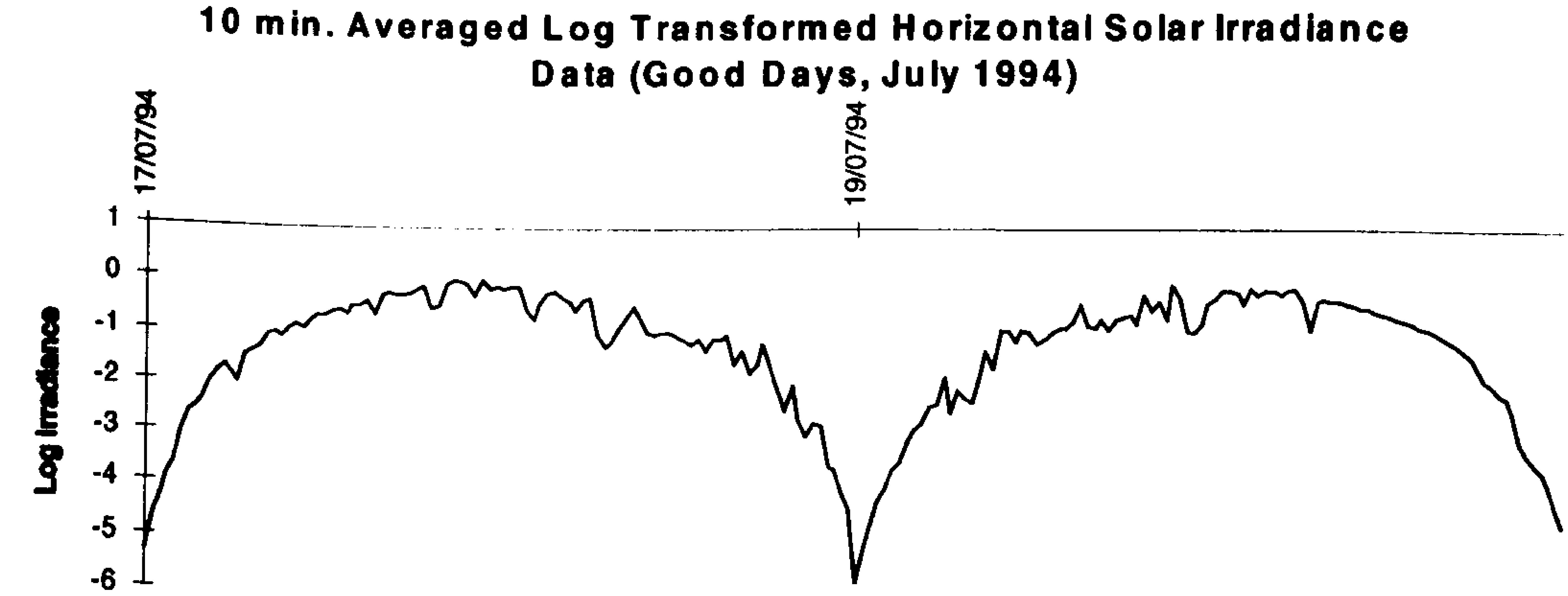
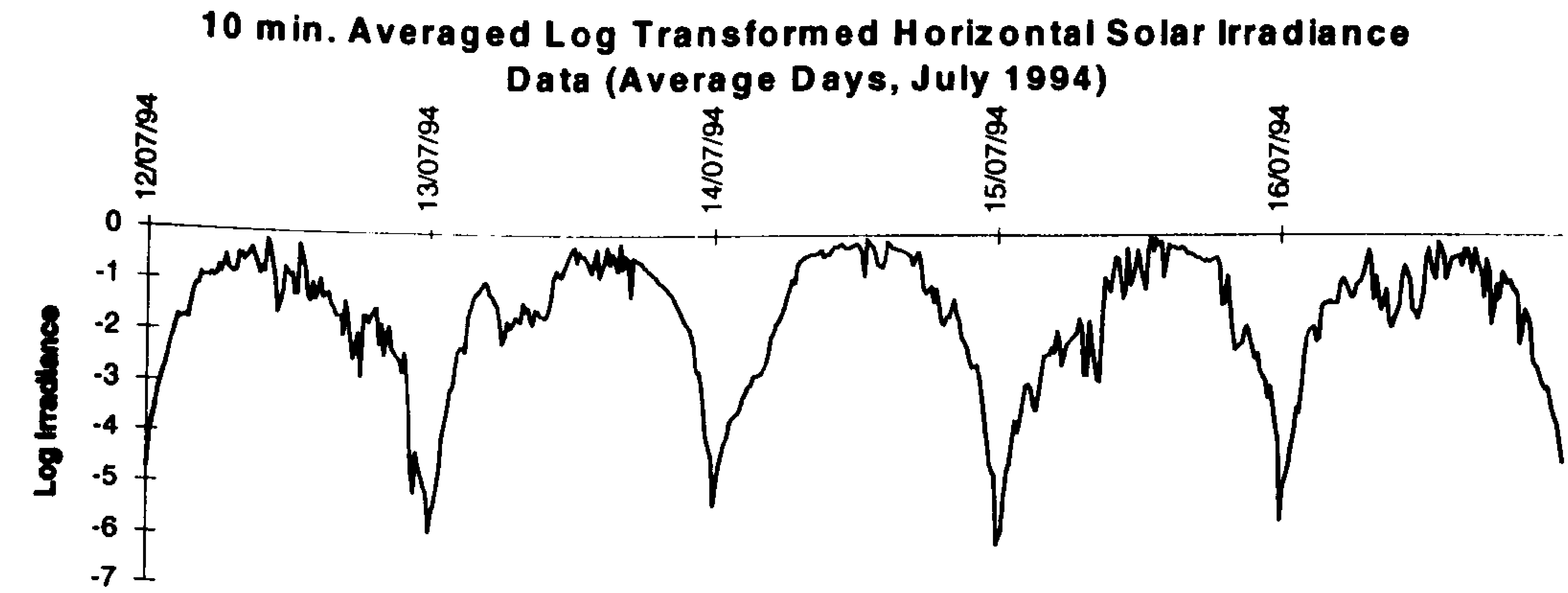


Figure 5.10.2 Log transformed Horizontal Solar Irradiance for 10 minute averages





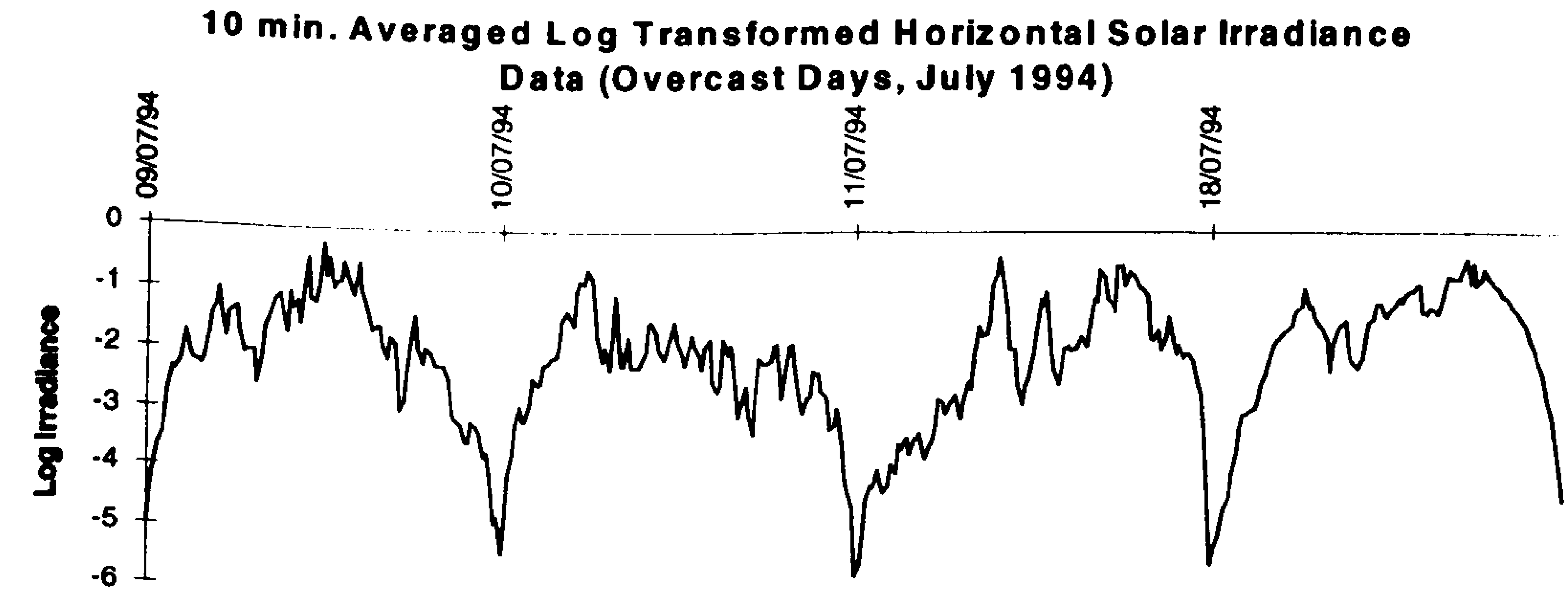
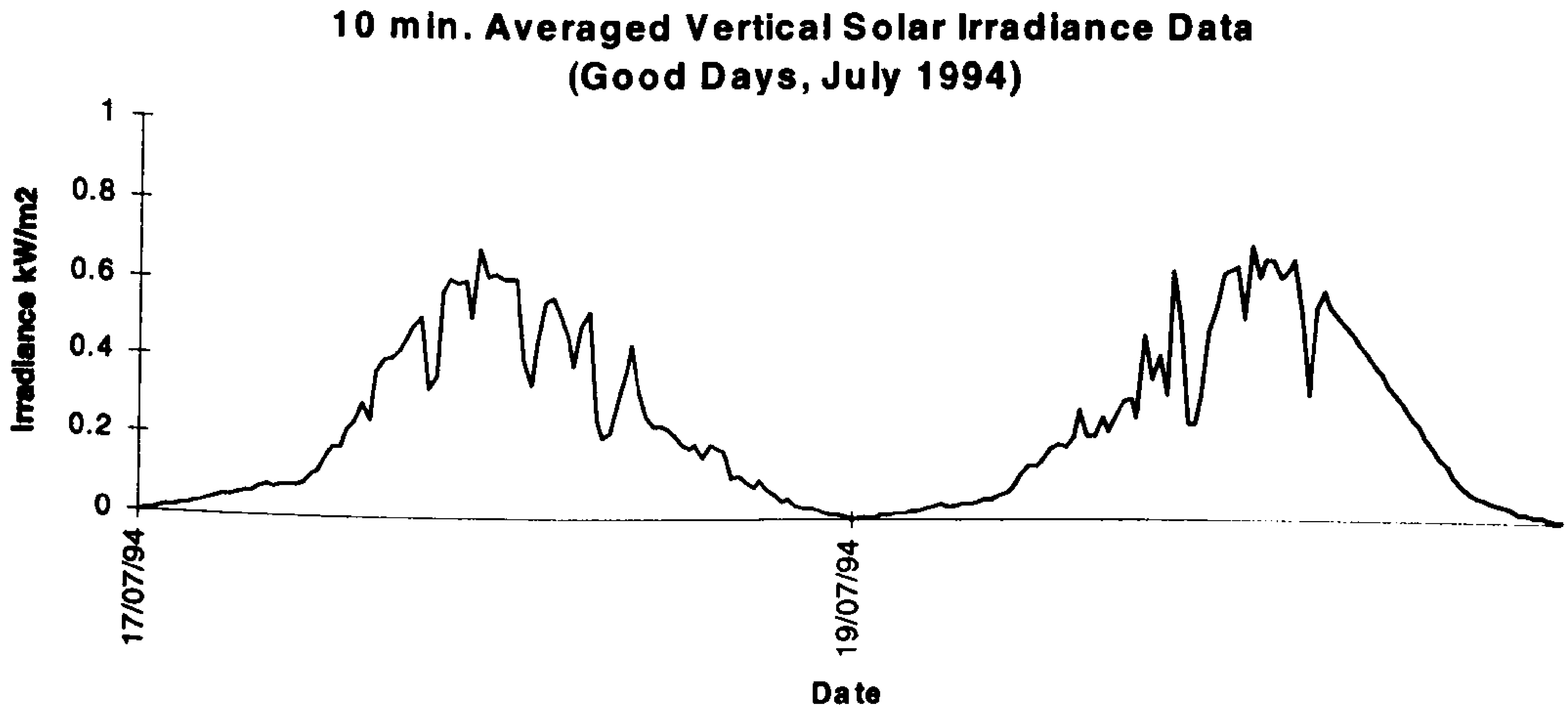
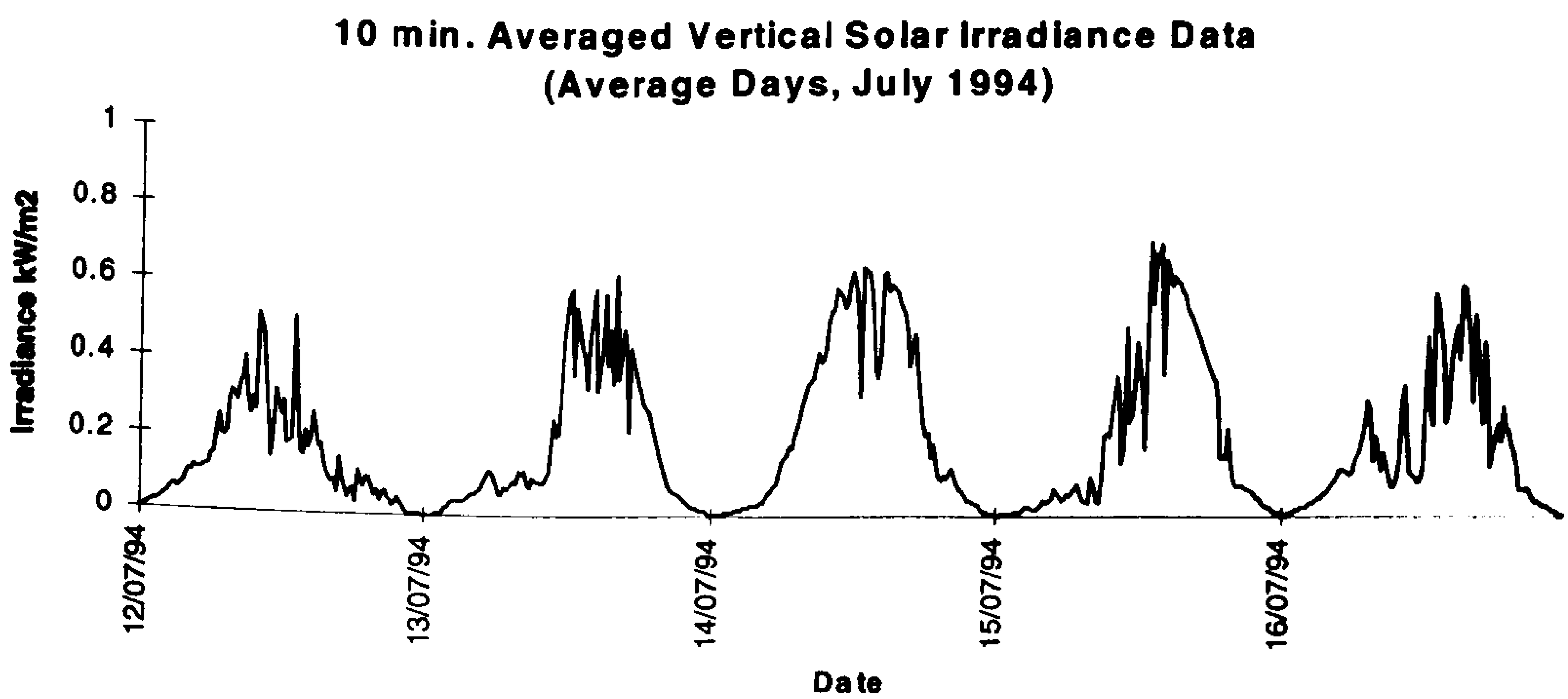


Figure 5.10.3 Vertical Solar Irradiance for 10 minute averages





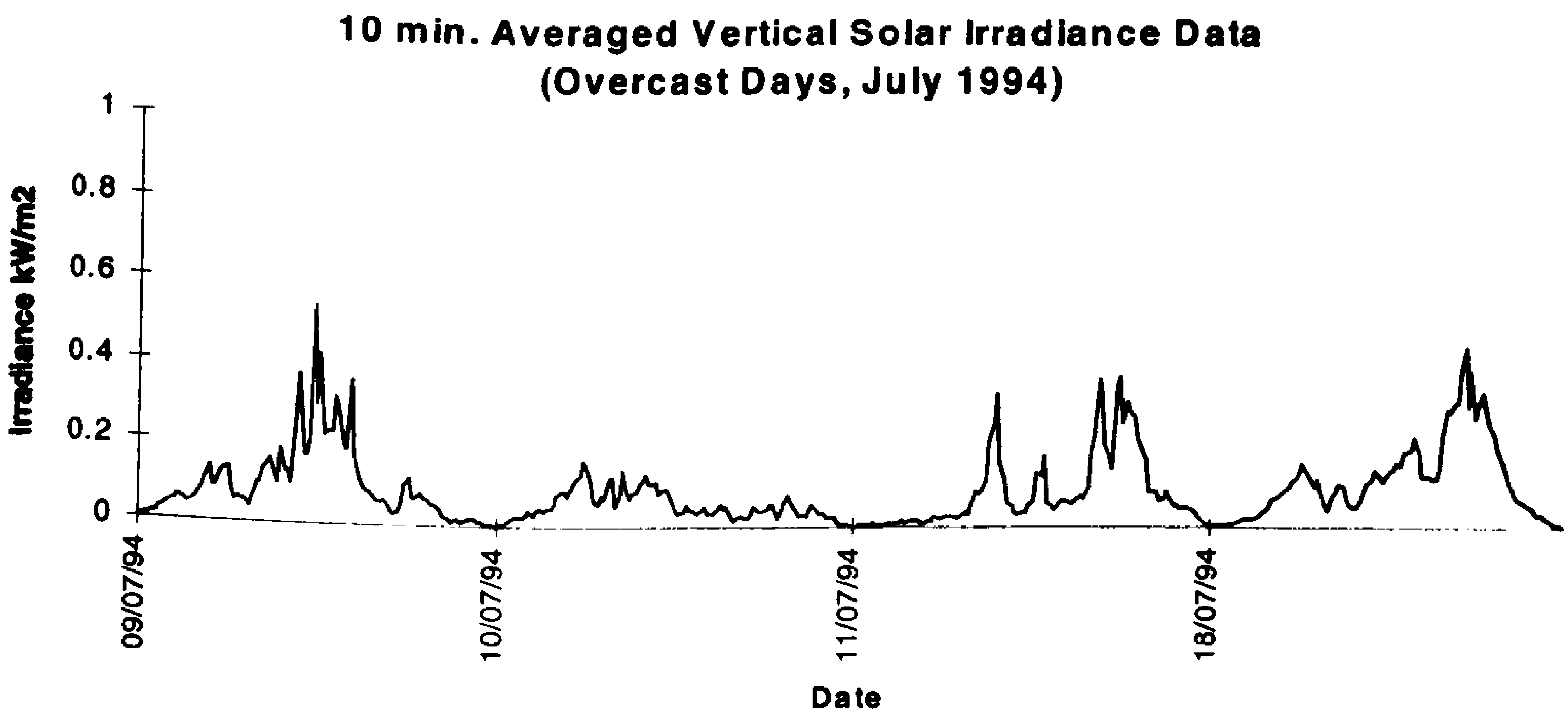
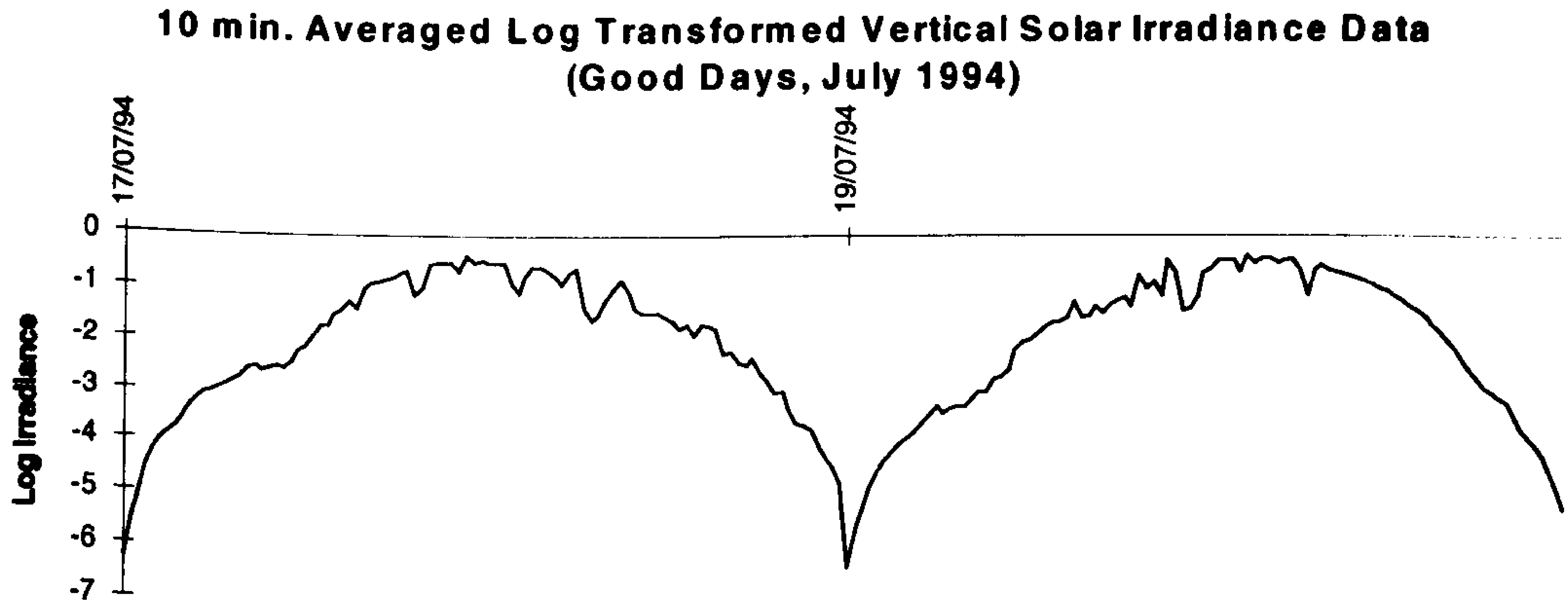
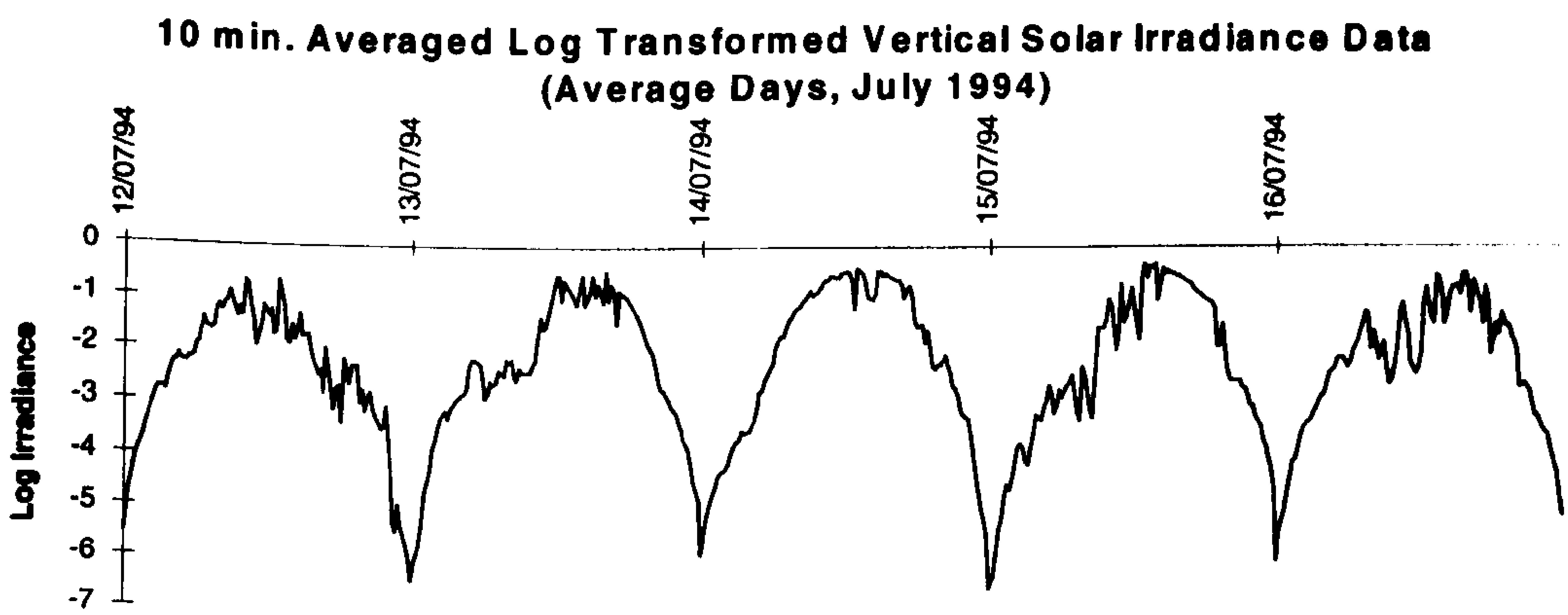
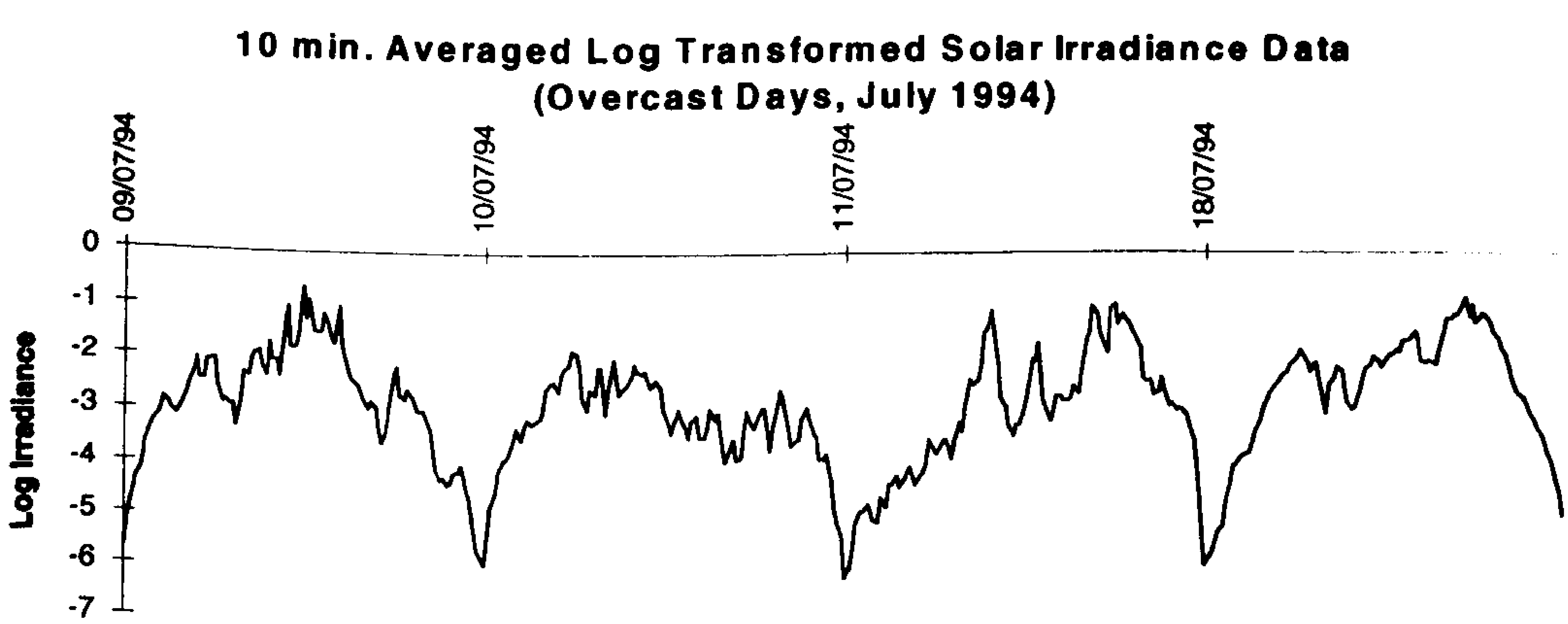


Figure 5.10.4 Log transformed Vertical Solar Irradiance for 10 minute averages







5.11. Summary of Results

Table 5.11.1 and Table 5.11.2 provide a summary of the average % R^2 values obtained from the analysis of the 1 minute solar irradiance data recorded in July 1994 and December 1995.

Table 5.11.1 Average %R^2 values by type of day obtained for July 1994

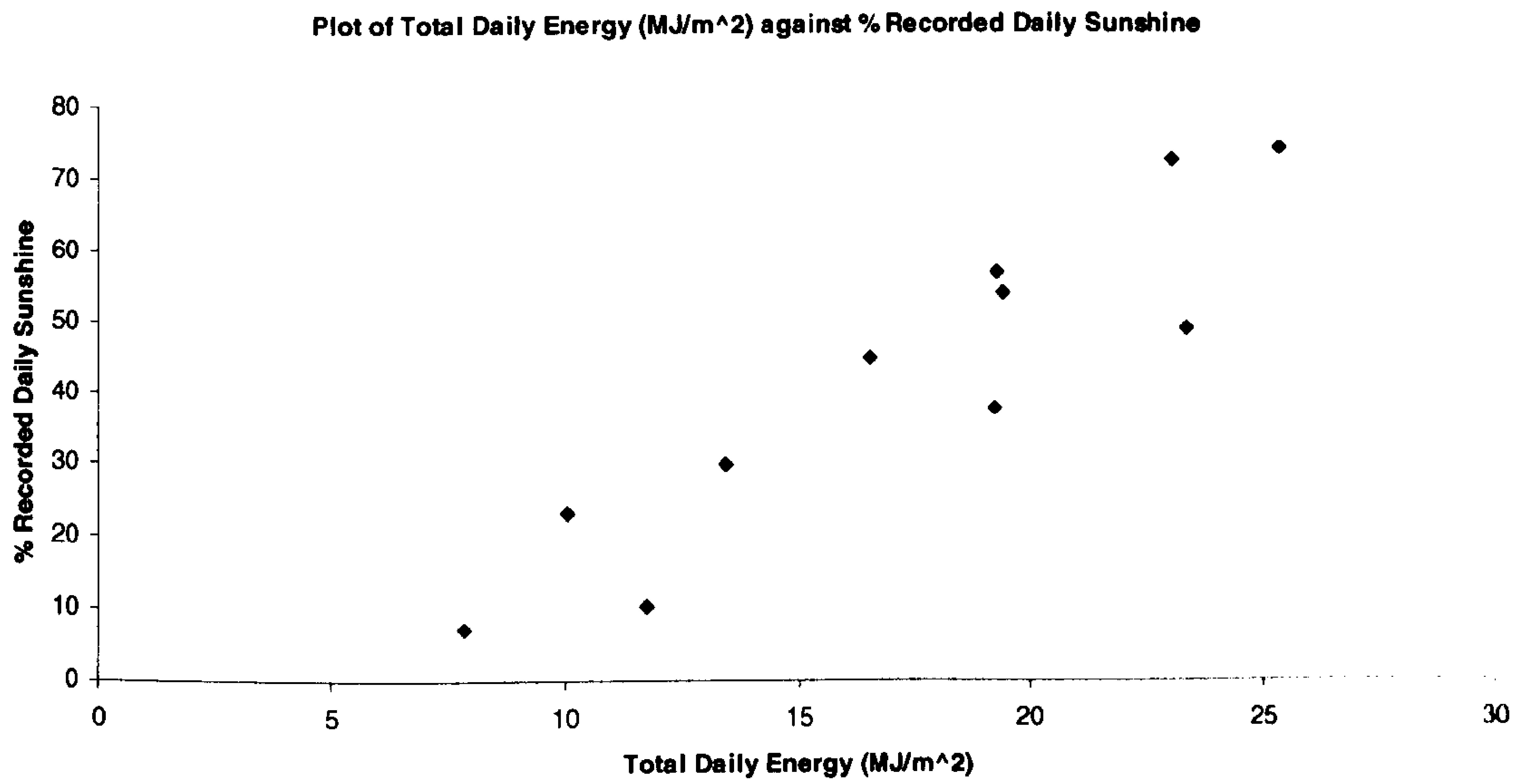
July 1994	Type of Day	Horiz	Log Horiz	Vert	Log Vert	Mean Original	Mean Log
	Good	86	97	89	98	87	97
1 min. inst.	Average	88	98	89	98	88	98
	Overcast	93	97	94	99	94	98
	Good	75	93	80	96	77	94
5 min. inst.	Average	73	93	76	95	75	94
	Overcast	78	98	80	95	79	97
	Good	70	89	75	94	72	91
10 min. inst.	Average	66	90	69	92	67	91
	Overcast	59	96	61	97	60	97
	Good	87	96	91	98	89	97
5 min. ave.	Average	85	96	86	97	85	96
	Overcast	86	95	87	96	86	96
	Good	88	96	91	97	89	96
10 min. ave.	Average	83	93	84	94	84	94
	Overcast	78	90	79	92	78	91

Table 5.11.2 Average %R^2 values by type of day obtained for December 1995

December 1995	Type of Day	Horiz	Log Horiz	Vert	Log Vert	Mean Original	Mean Log
	Good	98	98	98	99	98	98
1 min. inst.	Average	67	86	47	82	57	84
	Overcast	94	98	82	95	88	96
	Good	67	69	88	89	77	79
5 min. inst.	Average	31	54	19	49	25	51
	Overcast	72	77	62	71	67	74
	Good	37	47	68	86	53	66
10 min. inst.	Average	20	42	?	36	?	39
	Overcast	50	57	51	61	51	59
	Good	75	75	95	95	85	85
5 min. ave.	Average	61	70	40	68	50	69
	Overcast	83	85	68	81	76	83
	Good	55	54	86	89	70	71
10 min. ave.	Average	56	62	36	43	46	52
	Overcast	71	70	61	67	66	68

The daily total energy available per day in MJ/m^2 was also calculated for each day in the July 1994 data set and the correlation against the % sunshine recorded on that day was also calculated. Figure 5.11.1 displays the Total Energy available per day in MJ/m^2 in the July 1994 data set against percentage sunshine recorded on that day. The correlation coefficient was calculated to be 0.924, confirming a strong positive relationship.

Figure 5.11.1 Plot of Total Daily Energy per day against Percentage Sunshine recorded on that day (July 1994)



6. Discussion

6.1. Introduction

A majority of previous research, [13, 14, 25, 26, 29, 32, 33, 36, 41-52], has concentrated on data collected in countries located between latitudes 40^0 N and 40^0 S within essentially hot and dry climates. This study was carried out at a latitude of 55^0 N in an area subject to a cool temperate climate on the western margins. Here, the general levels of solar radiation are lower and cloud patterns can change rapidly. The majority of the previous studies were carried out at sites with a low population density. However, for PV technology to become commercially viable as a new sustainable energy source, it has to be located in areas of high population and be able to compete with other well-established forms of energy. This work was carried out within a city centre or urban environment, to monitor and analyse this situation.

In previous research, work has also concentrated on modelling global [11-13, 16-33, 35-37, 40-50, 52, 55, 57], direct [15, 23, 24, 30, 46, 50, 51, 53, 56, 57] and diffuse [14, 15, 18, 23, 24, 50, 54-58] irradiance on a horizontal surface. Irradiance on a vertical surface has received limited documentation, with researchers preferring to analyse horizontal radiation because of genuine meteorological interest, and because it is a useful and natural starting point in solar radiation analysis. In fact most studies use data recorded between 40^0 N and 40^0 S. In this study the more northerly latitude was considered to be an important factor and both horizontal and vertical solar irradiance were modelled separately, resulting in a better understanding of their individual characteristics.

6.2. Sampling Interval and Technique

In the area of solar radiation, the majority of previous researchers [35, 36, 41-49, 51, 52] have also concentrated on monthly, daily or hourly totals and averages of solar irradiance. This was generally because they were interested in PV system design, and as a natural progression, other meteorological variables such as wind speed, temperature and humidity were often measured and recorded over the same time intervals. Monthly, daily and even hourly averages are quite adequate for developing long-term averages of solar irradiation for a particular location over a length of time such as a month or a season. However, if there is interest in short term prediction then shorter intervals such as 10 minute or 1 minute data should be considered.

Suehrcke and McCormick [1988] analysed 1 minute instantaneous irradiance values recorded in Australia. They found that the fractional time distribution of daily insolation is not representative of instantaneous radiation. Morgan [1992] analysed diffuse, beam and global solar irradiances measured at 10 second intervals and averaged over 10 minutes, also for Australian data. He stated that the 10 minute averaging time was chosen as a compromise based on the requirements of the research project for which the data were collected. This was a subjective decision with no objective study or criteria stated.

Despite the wide variety of sampling intervals being used within the literature, there does not appear to have been a comprehensive study of sampling intervals and comparative results. In this thesis, a range of sampling intervals and sampling techniques were compared : 1, 5 and 10 minute instantaneous data, and 5, 10, 20, 30 and 60 minute averaged data.

In this study it has been demonstrated that increasing the sampling interval from 5 minute averaged data through to 20, 30 and 60 minute averaged data smoothes the data, as would be expected. To illustrate the effect of sampling interval, 1 minute data recorded on a typical day, 17th July 1994[6] , was used to create data sets of 5, 10, 20, 30 and 60 minute instantaneous values and data sets of 5, 10, 20, 30 and 60 minute averaged values. Increasing the sampling interval from 1 minute to 5 minute instantaneous values removes some of the data from the dataset. Figure 6.2.1 emphasises the amount of data lost resulting from increasing the sampling interval from 1 minute to 5 minute instantaneous values. Increasing the sampling interval through to 60 minute instantaneous values removes even more of the data. Figure 6.2.1 also displays the area under the solar irradiance curve, MJ/m^2.

Calculating the area under the graphs for each sampling interval, 1 min. through to 60 min. averages highlights that the total energy available, X, is not dependent on the averaging interval but the value of X^2 is. Table 6.2.1 displays the values obtained for data recorded on 17/7/94.

Table 6.2.1 Total Energy available on 17/7/94 at different sampling intervals

	1 min	5 min	10 min	20 min	30 min	60 min
Sum X	25.32	25.32	25.32	25.30	25.32	25.28
Sum X^2	0.9863	4.7784	9.4583	18.7334	28.0204	55.2809
Average	0.0256	0.1278	0.2557	0.5164	0.7670	1.5799
St. Dev	0.0185	0.0885	0.1746	0.3435	0.5185	1.0113
var	0.0003	0.0078	0.0305	0.1180	0.2689	1.0228
$E(X^2)$	0.0010	0.0242	0.0958	0.3847	0.8573	3.5190

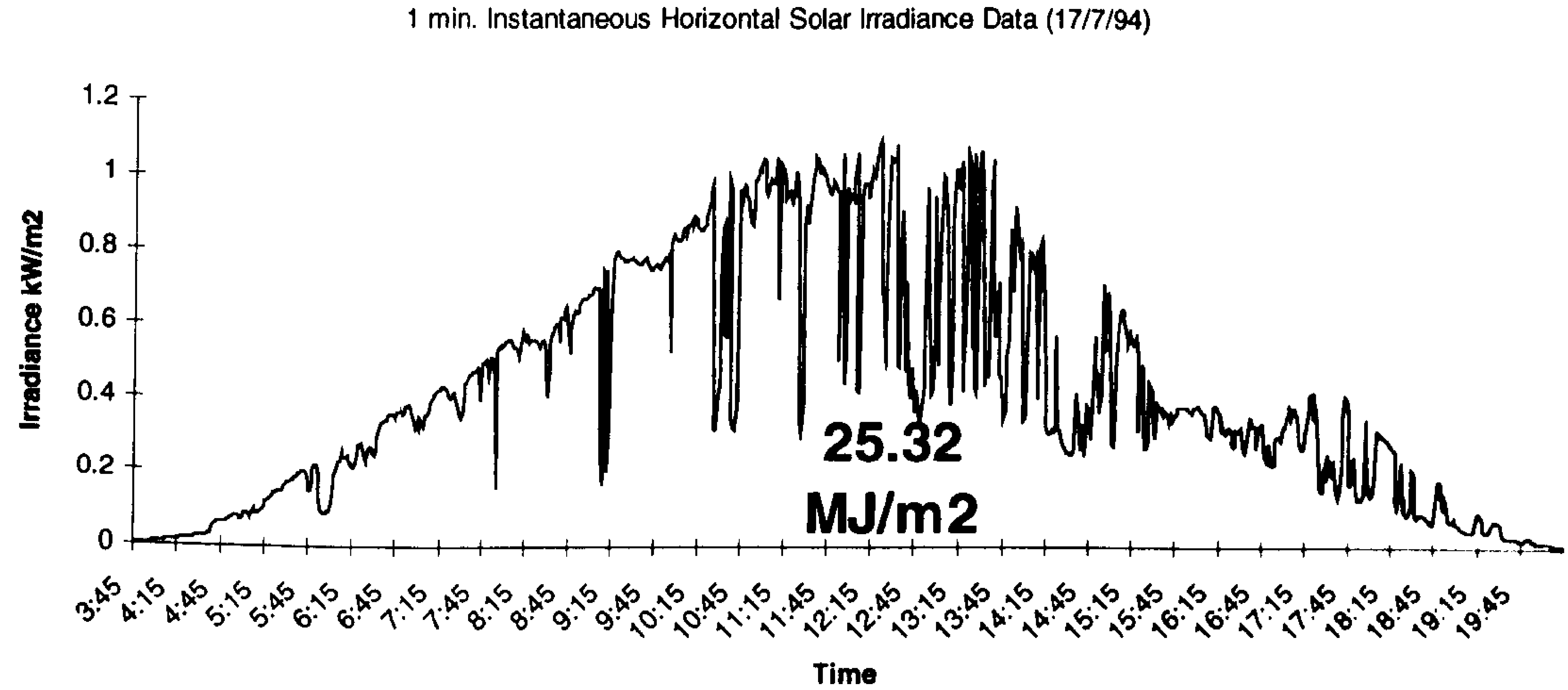
[6] The 17th July 1994 was selected as a typical good day, with 990 one-minute observations between 03:45 and 20:14.

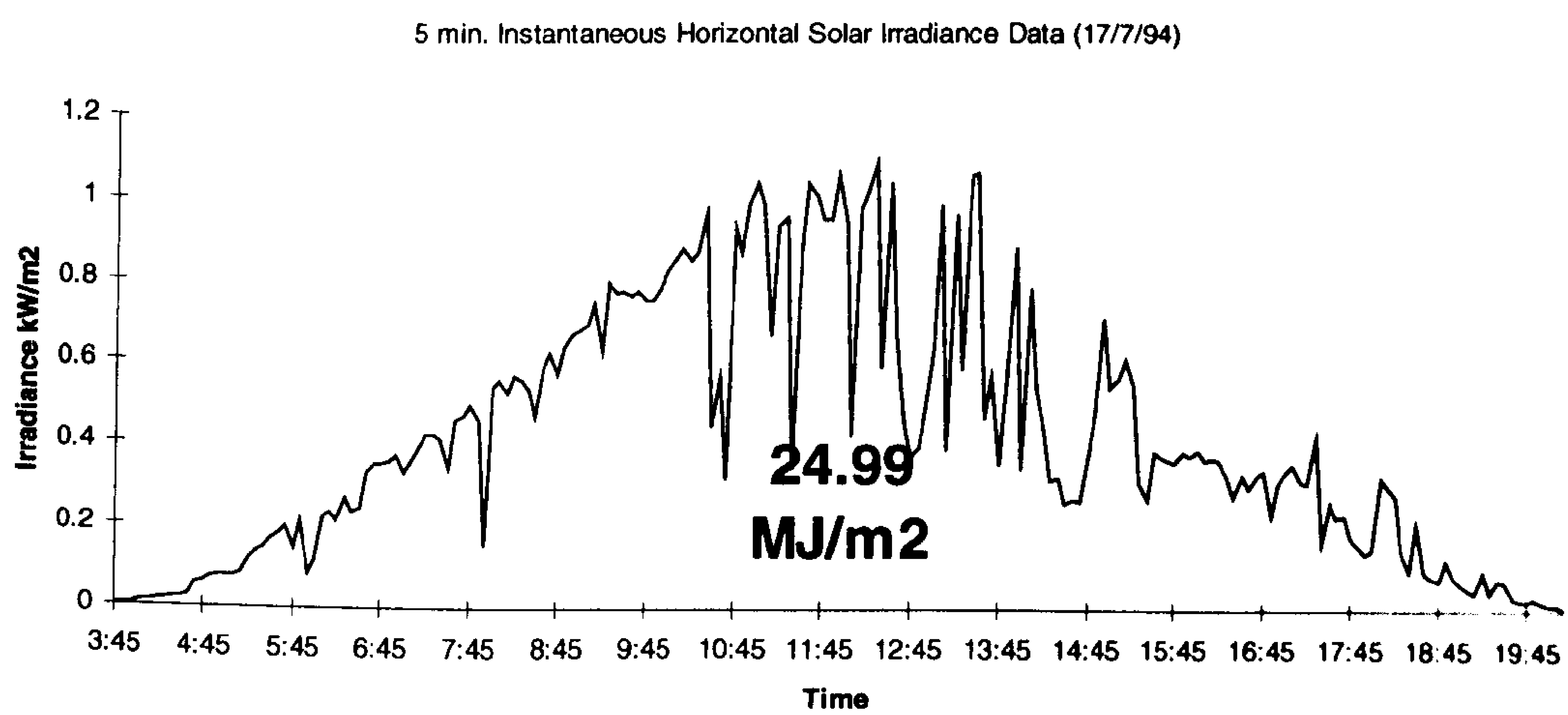
When comparing 1 minute instantaneous data with 5 and 10 minute averaged data the smoothing of the data by averaging is very obvious. The larger sampling intervals reduce the magnitude of peaks / troughs and decrease the number of turning points. When comparing 5 minute instantaneous data with 5 minute averaged data, Figure 6.2.2, again averaging smoothed the data. This was further emphasised when comparing 10 minute instantaneous data with 10 minute averaged data, Figure 6.2.3, where peaks / troughs are further reduced in magnitude, some are even lost, and the number of turning points is further reduced.

Increasing the sampling / averaging interval from 10 minute averages through 20, 30 and 60 minute averages further reduces the magnitude and number of peaks / troughs, with some peaks / troughs being eradicated in the averaging. Figure 6.2.4 displays 1 minute instantaneous, 5, 10, 20, 30 and 60 minute averaged data for 17th July 1994. It is obvious that essential information is lost as the sampling interval is increased to 60 minute averages. For example in the 1 minute instantaneous data there is a trough just before 14:45, indicated by the parallel lines, which is more obvious in the 5 minute and 10 minute data and is still visible in the 20 and 30 minute data but is lost when the sampling interval is increased to 60 minutes. It is important to retain this type of feature for short term forecasting, keeping a balance between 'noise reduction' and retention of the 'smaller features'. This loss of information as the sampling interval is increased is also observed in the data sets DEC93, JUNE94, JUL94, DEC94, JUNE95 DEC95 and JUNE95 (see Table 2.2.1 and Table 2.2.2), which are displayed in their relevant sections within the results chapter.

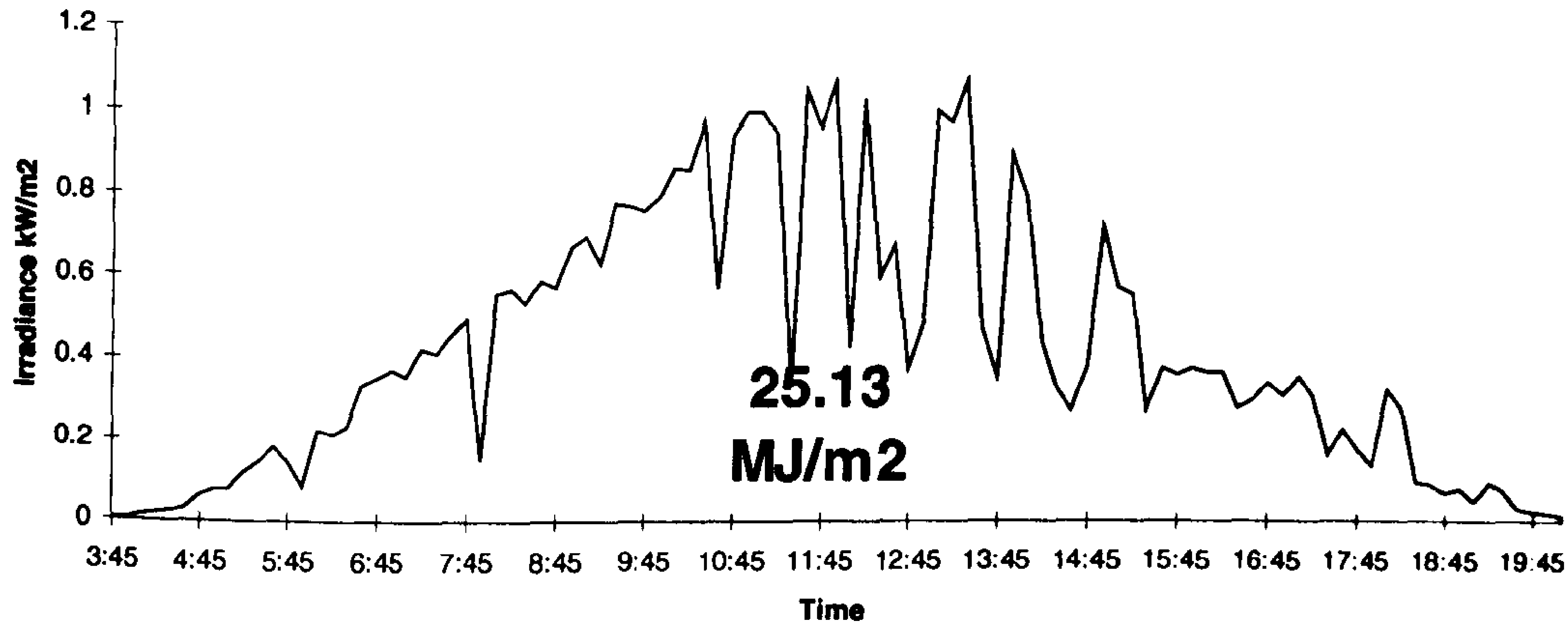
In the work which follows I attempt to estimate / evaluate this loss of information associated with each sampling interval.

Figure 6.2.1 Instantaneous Horizontal Solar Irradiance recorded on 17th July 1994

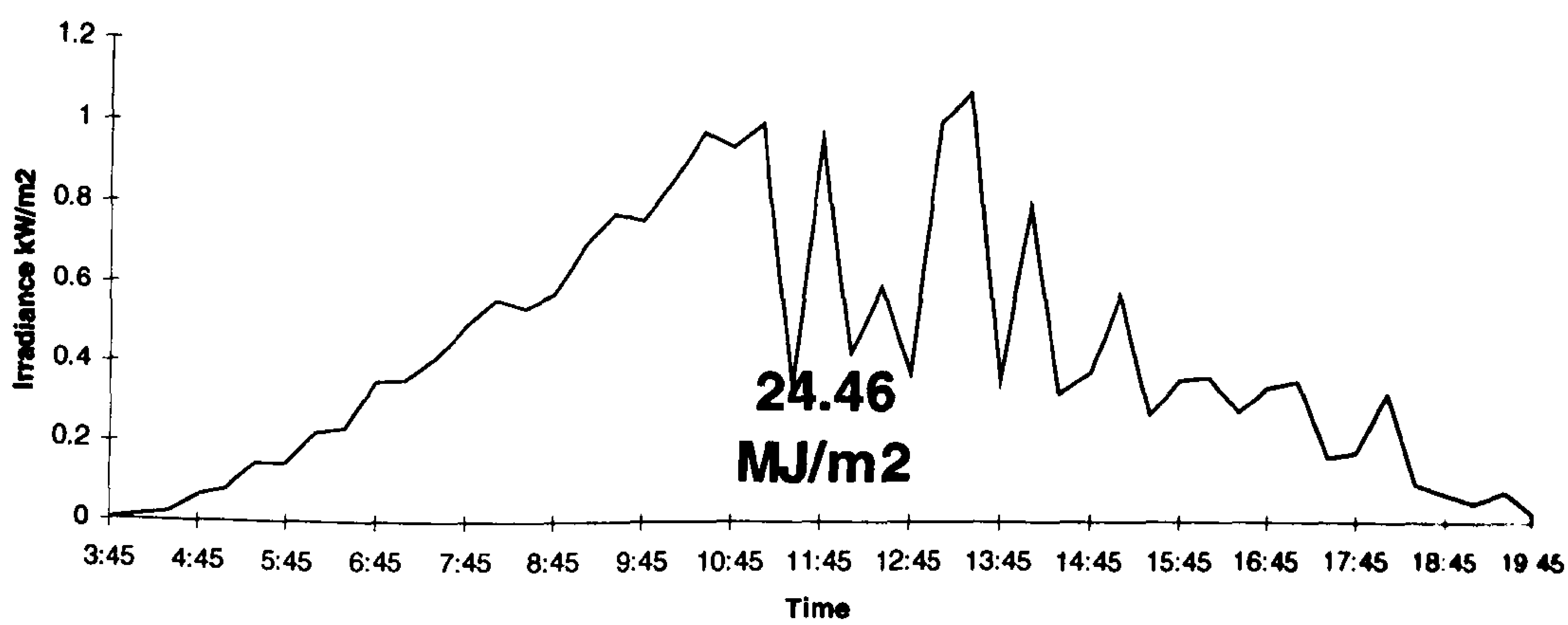


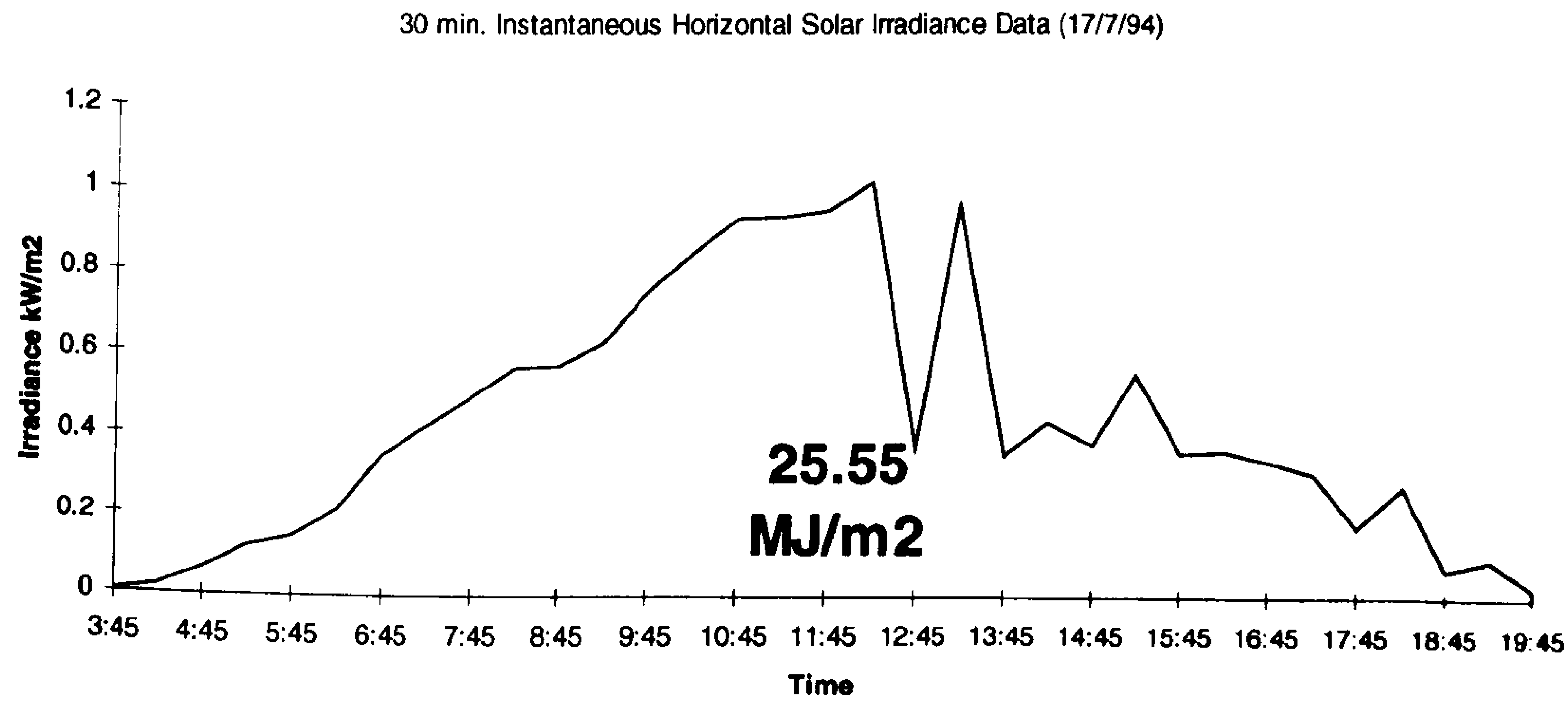


10 min. Instantaneous Horizontal Solar Irradiance Data (17/7/94)



20 min. Instantaneous Horizontal Solar Irradiance Data (17/7/94)




30 min. Instantaneous Horizontal Solar Irradiance Data (17/7/94)
Irradiance kW/m2
1.2
1
0.8
0.6
0.4
0.2
0
25.55
MJ/m2
3:45
4:45
5:45
6:45
7:45
8:45
9:45
10:45
11:45
12:45
13:45
14:45
15:45
16:45
17:45
18:45
19:45
Time

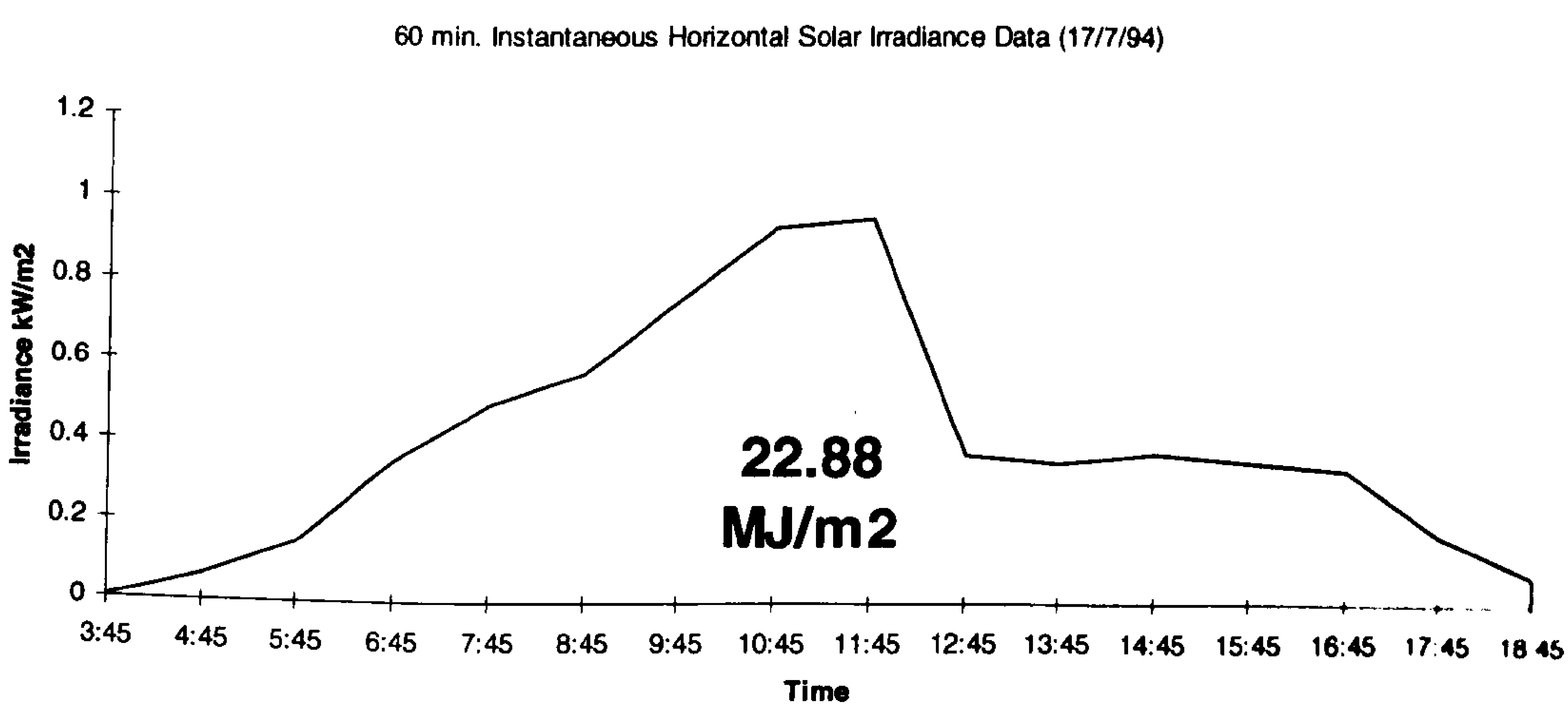

60 min. Instantaneous Horizontal Solar Irradiance Data (17/7/94)
Irradiance kW/m2
1.2
1
0.8
0.6
0.4
0.2
0
22.88
MJ/m2
3:45
4:45
5:45
6:45
7:45
8:45
9:45
10:45
11:45
12:45
13:45
14:45
15:45
16:45
17:45
18:45
Time

Figure 6.2.2 Instantaneous versus Averaged values

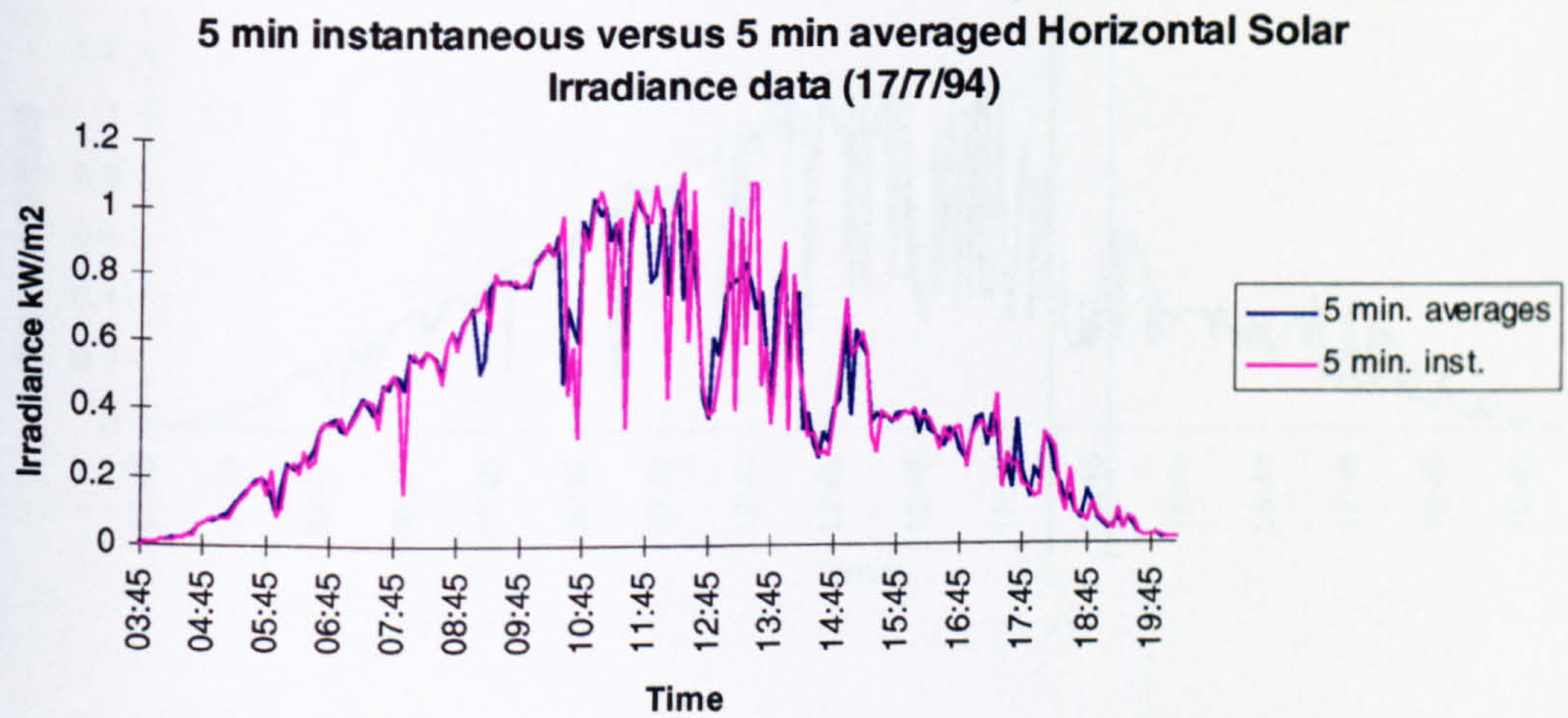


Figure 6.2.3 Instantaneous versus Averaged values

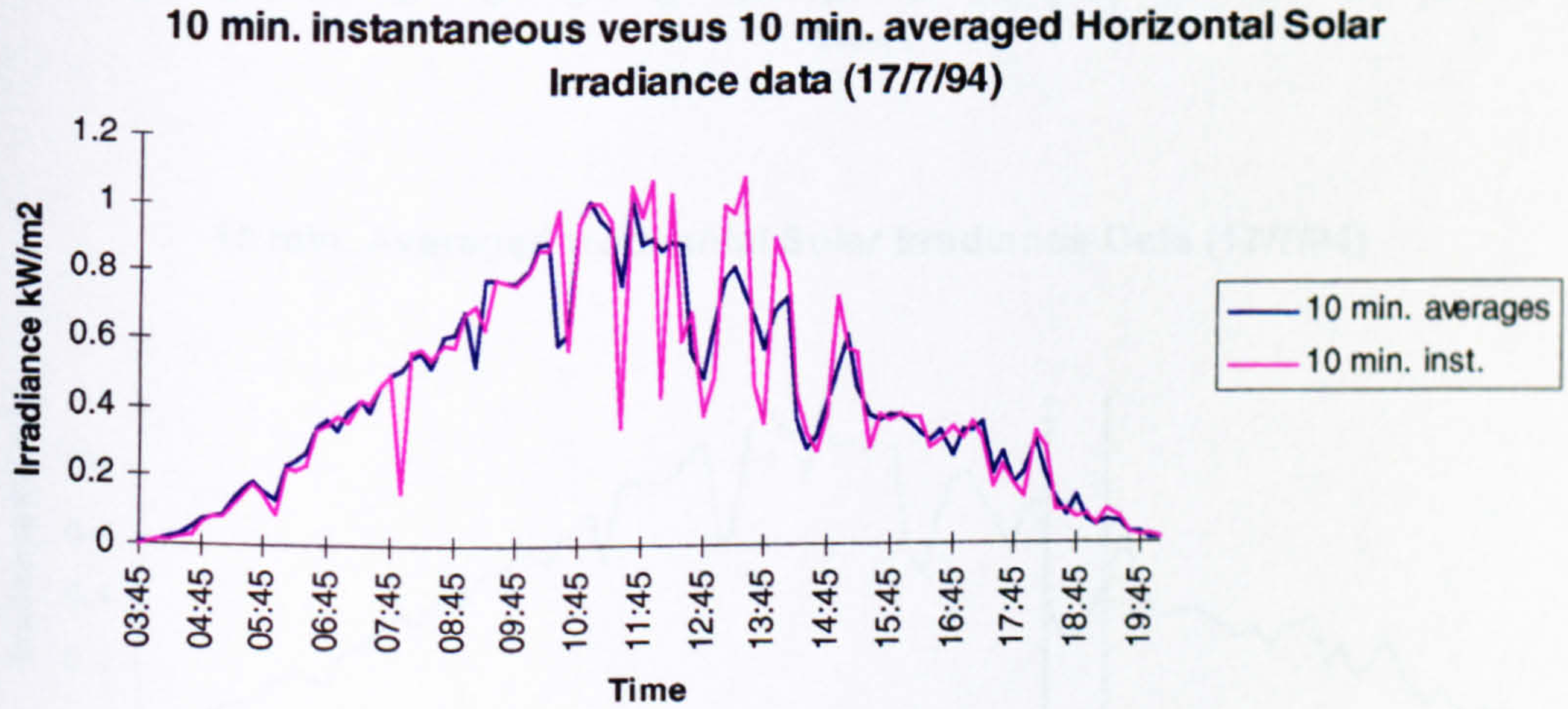
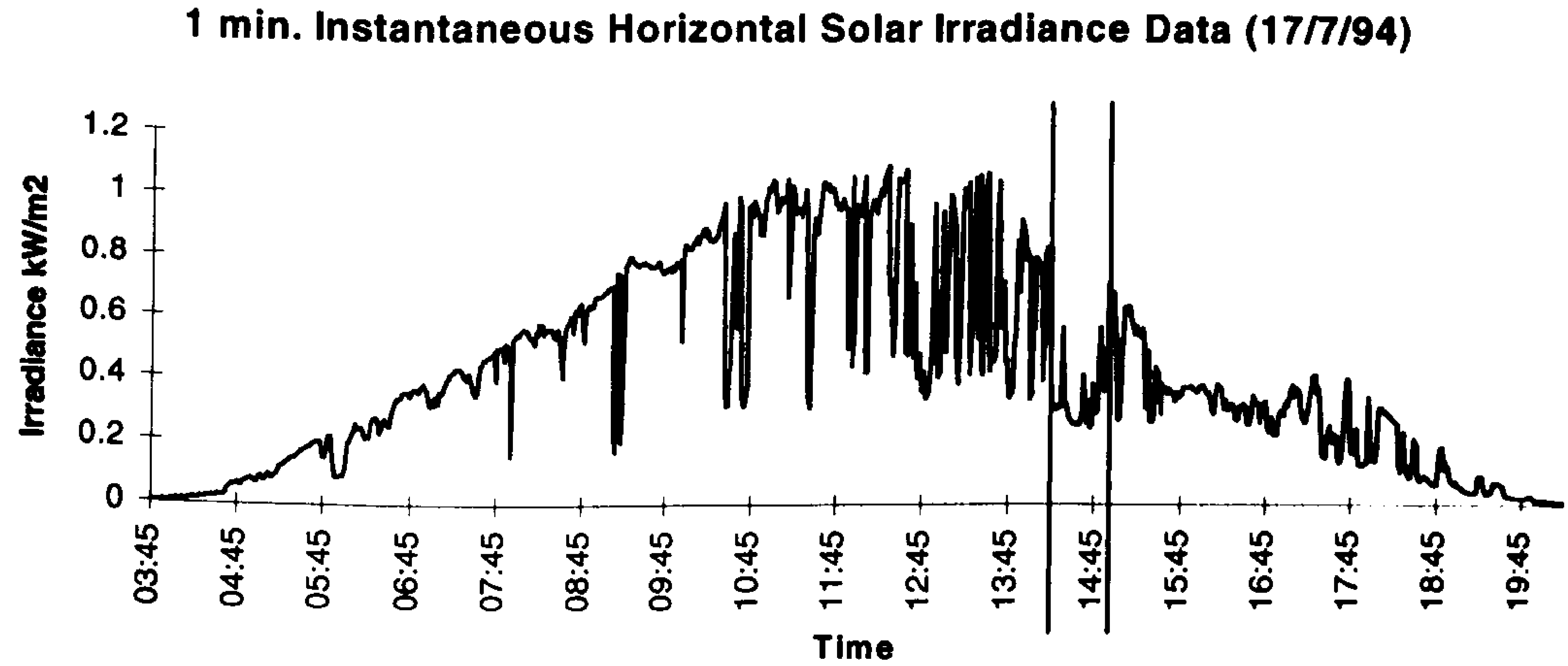
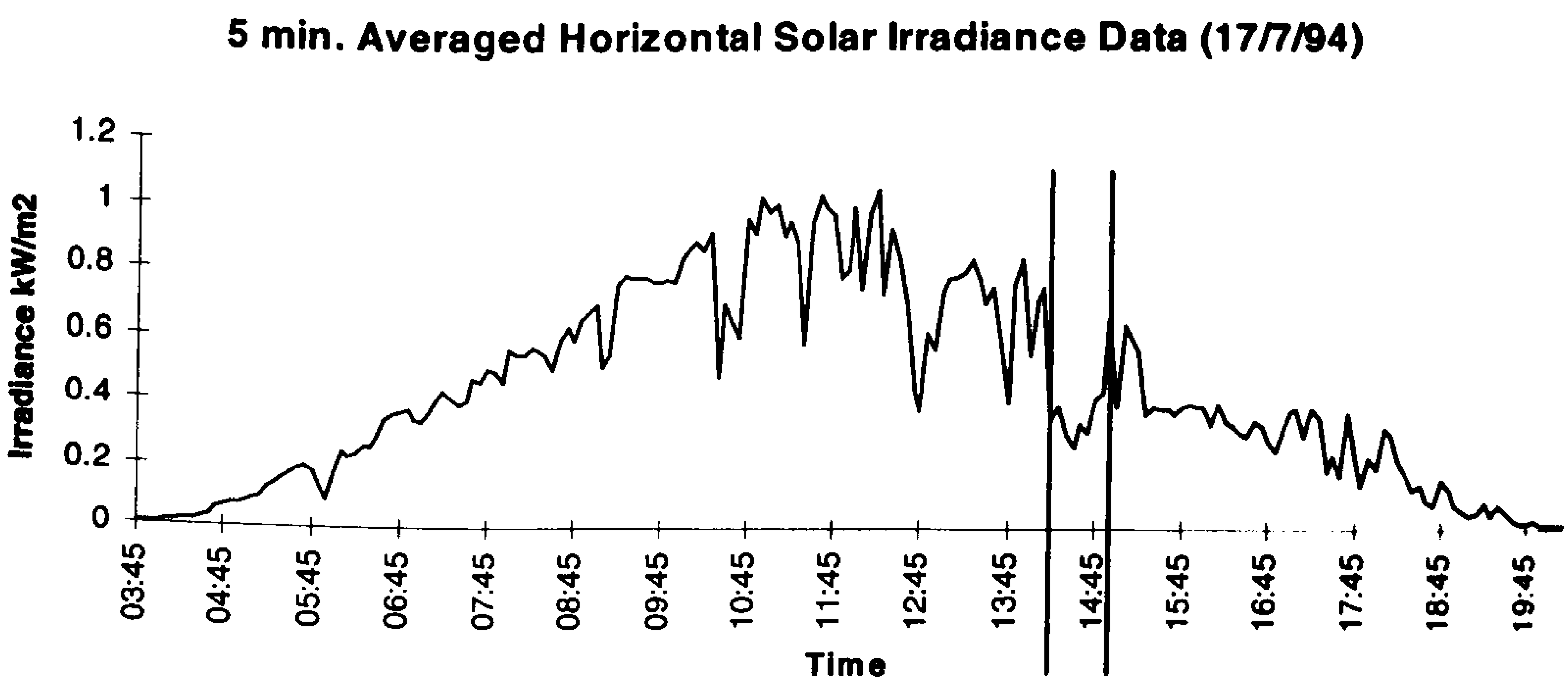
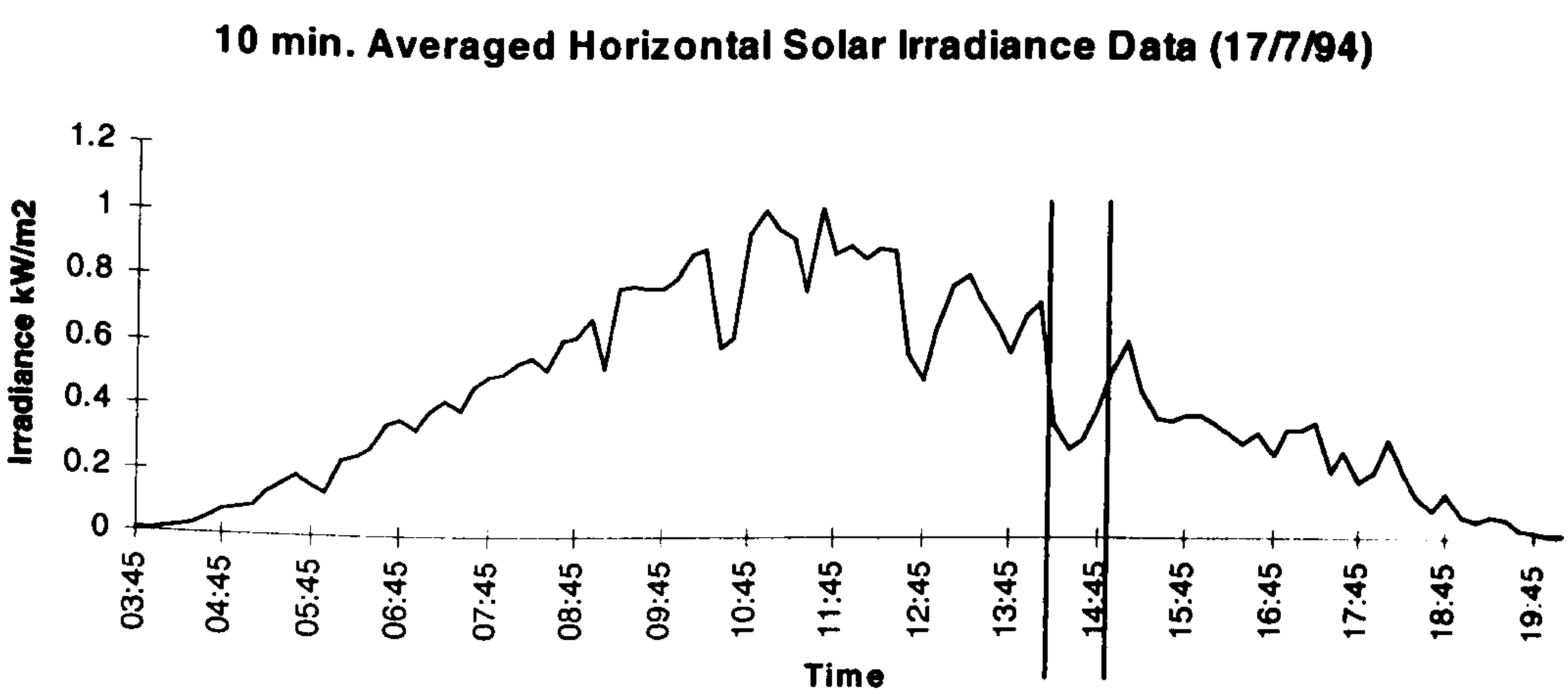


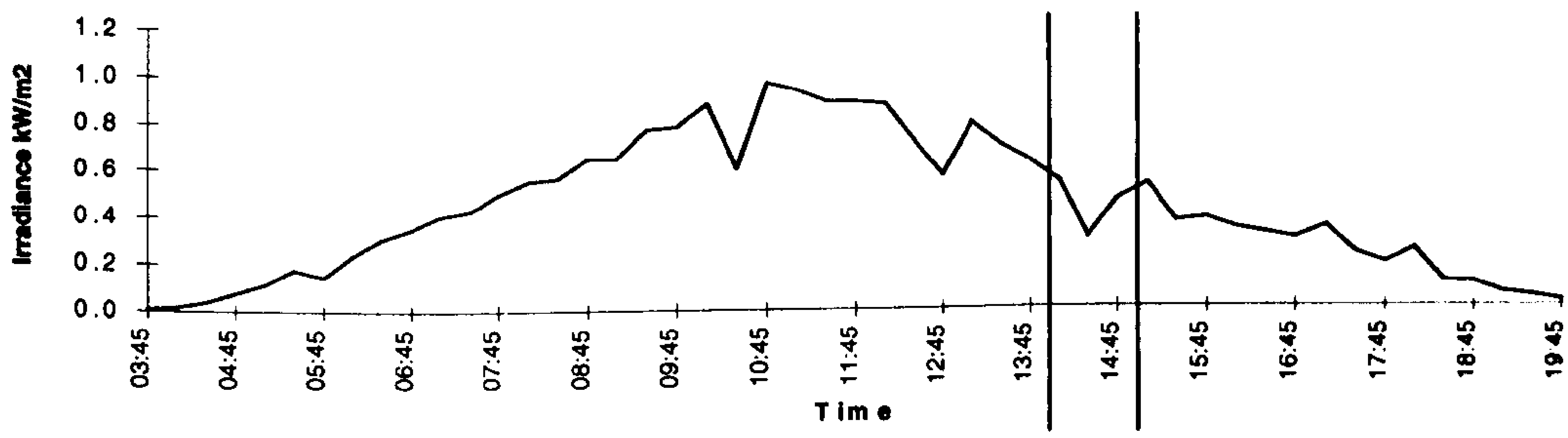
Figure 6.2.4 One-minute Instantaneous with 5 and 10 minute averaged Horizontal Solar Irradiance recorded on 17th July 1994



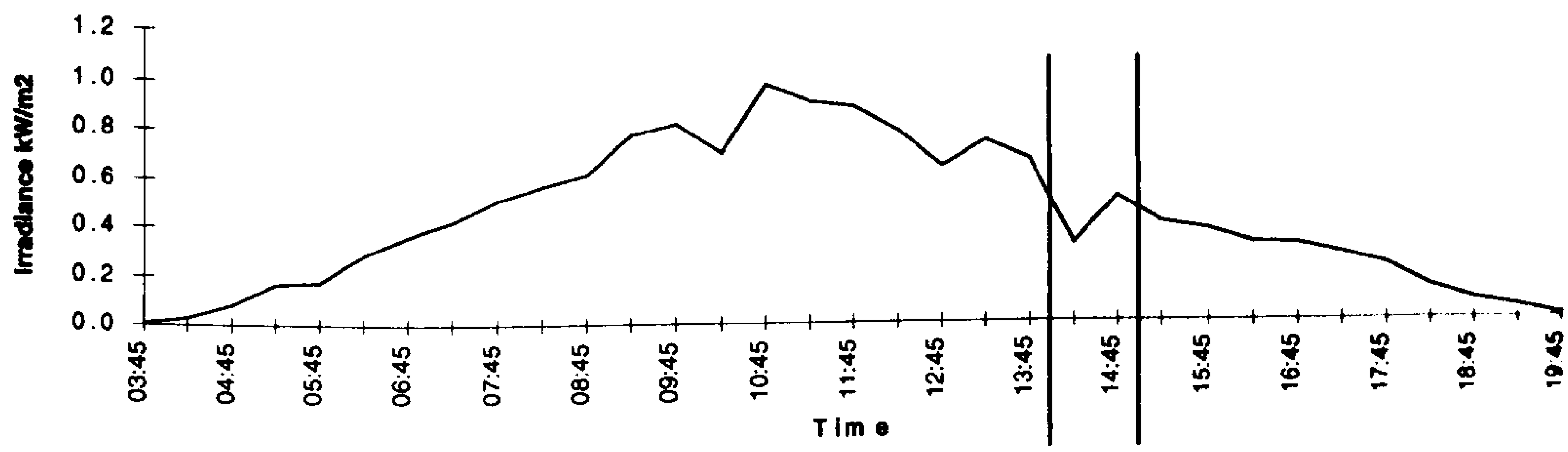




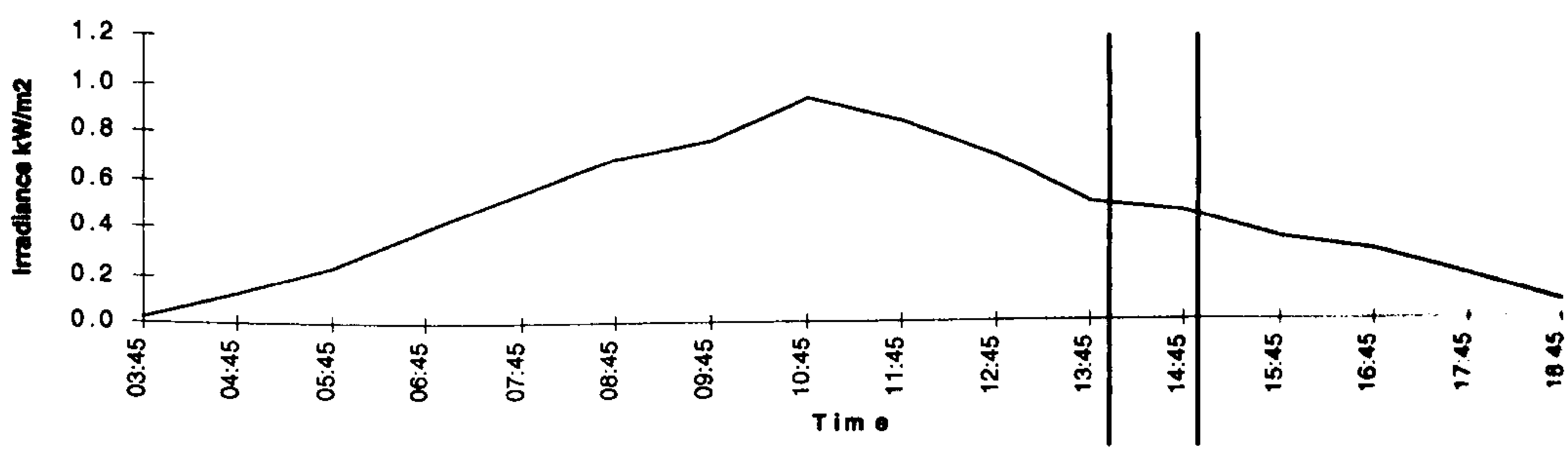
20 min. Averaged Horizontal Solar Irradiance Data (17/7/94)



30 min. Averaged Horizontal Solar Irradiance Data (17/7/94)



60 min. Averaged Horizontal Solar Irradiance Data (17/7/94)



6.3. Autocorrelation Coefficients

The autocorrelation coefficient can be used to measure the effect of increasing the sampling interval - the main advantage being that this coefficient is dimensionless and can therefore be used as a direct comparison between different data sets with different sampling intervals. This coefficient also plays an important role in building ARIMA models to be fitted to recorded data.

Gansler et al [1994] calculate the minute clearness index for three locations, Atlanta, Albany and San Antonio, in the USA. The hourly average lag-one autocorrelation coefficient was calculated for each hour for all twelve months for each location, with values ranging from 0.7 to 0.9. They concluded that there was little systemic variation of the autocorrelation coefficient with changes in the hourly clearness index, but there was a seasonal trend. They found that for a given hour, φ_1 (the autocorrelation coefficient at lag 1) is higher in winter months than summer months. There was a general trend with respect to the hour of the day. Central hours of the day typically have a lower value of φ_1 than early or late hours. Goh and Tan [1977] used hourly totals and daily totals for Singapore while Brinkworth [1977] used daily totals in the UK. However, Aguiar and Collares-Pereira [1992] stated that the computation of the autocorrelation at lag i, φ_i ,is difficult in the case of hourly radiation because of the short length of the daily sequences which produce high estimates of φ_1 (0.6 - 0.9), stemming from the existence of a systemic daily trend in the data.

In this study, shorter sampling intervals are compared for data recorded at Newcastle upon Tyne, UK. From the original horizontal and vertical solar irradiance data it was apparent that the variance was not constant, i.e. as the mean level increased the variance increased. This indicated that the original data required a transformation in order to stabilise the variance, which is also a requirement for modelling at a later stage. Thus the original horizontal and vertical solar irradiance data and log transformed horizontal and vertical solar irradiance data were modelled and compared within this study.

The general conclusion for both winter and summer data is that the lag 1 autocorrelation for horizontal and vertical solar irradiance data decreases as the sampling interval increases. For example the lag 1 autocorrelation coefficients for 10 minute averaged winter 1993 horizontal and vertical solar irradiance data are 0.92 and 0.91, respectively. This falls to 0.86 and 0.85 respectively for 20 minute averaged data and to 0.79 and 0.79 for 30 minute averaged data, which then drops to 0.52 and 0.62 for 60 minute averaged data. This is as would be expected with increasing the sampling interval, and similar trends are evident in winter 1994, winter 1995, summer 1994 and summer 1995 data.

Summer data in general were found to have a larger lag 1 autocorrelation coefficient than winter data, whether it be horizontal, vertical, log transformed horizontal or log transformed vertical data. For example, 60 minute averaged winter horizontal data has a mean lag 1 autocorrelation coefficient of around 0.56, while summer data has a mean lag1 around 0.76. This difference is also apparent with vertical data where winter data has a mean lag 1 of 0.63 and summer data has a mean lag 1 of 0.78, a substantial difference of 0.25. At lag k, where k is the length of the daily cycle, the winter autocorrelation coefficients are greater than summer coefficients for the horizontal plane (averaging 0.36 and 0.29 respectively) while summer coefficients are greater than winter on the vertical plane (averaging 0.12 and 0.32 respectively).

There is a very strong similarity between the lag 1 autocorrelation coefficients of horizontal and vertical solar irradiance data in both summer and winter. This is also apparent at lag k e.g. the June 1995 lag k coefficient of 10 minute averaged horizontal and vertical data are 0.28 and 0.26 respectively. Most differences between horizontal and vertical autocorrelation coefficients in summer data are of the order 0.05 or less while in winter the differences range from 0.14 to 0.30.

Lag k coefficients were significant for horizontal winter data at all sampling intervals but only just significant for horizontal summer data at the 60 minute averaged sampling interval. Similarly, for transformed data, the lag k autocorrelation coefficient was significant at all sampling intervals for horizontal winter data but only just significant at the 60 minute averaged sampling interval for horizontal summer data. First differenced log transformed vertical data has consistent significant lag k autocorrelation coefficients only at the 60 minute averaged sampling interval.

Similar conclusions were made when comparing the results for 1, 5, 10 minute instantaneous with 5 and 10 minute averaged horizontal and vertical solar irradiance data. The same characteristic increase in the sampling interval results in a decrease in the lag 1 autocorrelation coefficient. Table 6.3.1 displays the average lag 1 autocorrelation coefficients for each sampling interval in the July 1994 and December 1995 data sets. From this table it is clear that the lag 1 autocorrelation coefficient for 1 minute instantaneous data is greater than any other sampling interval. It is also apparent that the lag 1 coefficients for 5 and 10 minute averaged data are greater than the coefficients for 5 and 10 minute instantaneous data, respectively. In comparing the 5 minute instantaneous with 5 minute averaged data the differences are marginal, of the order 0.06, while 10 minute instantaneous and averaged data have differences of the order 0.1. Taking a log transformation of the data and then calculating the lag 1 autocorrelation coefficients results in a higher coefficient for both horizontal and vertical data. For July 1994 the lag 1 autocorrelation coefficients for vertical data are greater than horizontal data, log transformed or not. The opposite is true for December 1995 data where the horizontal coefficients are greater than the vertical coefficients. When comparing 5 minute and 10 minute data there is less difference between instantaneous and averaged data, for 5 minute data differences of the order 0.01 and for the 10 minute data of the order 0.02. This was due to the stabilisation of the variance by using a log transformation.

Table 6.3.1 Average Lag 1 Autocorrelation Coefficients by sampling interval for July 1994 and December 1995

	1 min. inst.	5 min. inst.	10 min. inst	5 min. average	10 min. average
July'94 Horiz	0.939	0.849	0.763	0.913	0.881
July'94 Vert	0.946	0.866	0.787	0.924	0.889
July'94 Log Horiz	0.981	0.922	0.857	0.937	0.883
July'94 Log Vert	0.985	0.939	0.884	0.989	0.904
Dec'95 Horiz	0.931	0.778	0.635	0.861	0.785
Dec'95 Vert	0.858	0.654	0.485	0.775	0.712
Dec'95 Log Horiz	0.965	0.821	0.699	0.864	0.771
Dec'95 Log Vert	0.954	0.807	0.669	0.858	0.763

Also, suppose we have a continuous time series z_t which is weakly stationary. That is for all t:

$$\mu = \mathrm{E}(z_t) = \int_{-\infty}^{\infty} z_t dF(z_t) = \int_{-\infty}^{\infty} z_t dz$$

Eq. 6.3.1

$$\sigma^2 = \mathrm{E}(z_t - \mu)^2 = \int_{-\infty}^{\infty} (z_t - \mu)^2 dF(z_t) = \int_{-\infty}^{\infty} (z_t - \mu)^2 dz$$

Eq. 6.3.2

Further, any pair of z's, z_t and z_s ($t>s$, $t \neq s$) have autocovariance

$$\gamma_{t-s} = E\{(z_t - \mu)(z_s - \mu)\} = \gamma_{-(t-s)}$$

Eq. 6.3.3

and the corresponding autocorrelation

$$\rho_{t-s} = \frac{\gamma_{t-s}}{\sigma^2} = \rho_{-(t-s)}$$

Eq. 6.3.4

observations on this continuous time series are taken instantaneously every minute. That is at times .,.,.t-1, t, t+1, t+2,.,.,.. Using this sampling scheme the theoretical autocovariance at lag5, γ'_5, is given by

$$\gamma_5^1 = E(z_t - \mu)(z_{t+5} - \mu).$$

Eq. 6.3.5

Observations may similarly be taken instantaneous every 5 minutes. That is at times , , ,t-5, t, t+5, , ,. Under this new sampling scheme the theoretical autocorrelation at lag1, γ''_1, is given by

$$\gamma_1^{''} = E(z_t - \mu)(z_{t+5} - \mu).$$

Eq. 6.3.6

Hence, for instantaneous observations, the lag5 theoretical autocorrelation coefficient for 1 minute instantaneous observations on the time series is the same as he lag1 theoretical autocorrelation coefficient for 5 minute instanteous observations on the same series. Similar relationships can be obtained for 1 minute and 10 minute instanteous data. This relationship is not applicable for the 5 minute averaged data as 5 consecutive one minute observations are averaged to create this series. The autocorrelation between the 5 averaged values influences the autocorrelation coefficients on the 5 minute average series. Obviously the underlying process is required before this may be assessed.

6.4. Modelling of Solar Irradiance

The astronomical model of Eq. 1.2.6 was used to calculate the theoretical solar irradiance on a horizontal surface outside of the atmosphere, at 1 minute intervals. This was carried out for several days from both summer and winter data, and when compared with actual observed data was found to be a consistent overestimate. This is illustrated for a typical day, 17^{th} July 1994, in Figure 6.4.1. These results were expected as the observed irradiance travels through the earth's atmosphere where transmittance conditions such as cloud cover, air pollution and reflections reduce the amount of irradiance reaching the earth's surface. Goh and Tan [1977] stated that a given solar radiation should contain all the essential characteristics of the past behaviour of solar radiation at the measuring station. Various graphical and mathematical models, as in [70, 71, 72], are attempts to satisfy this criterion, as discussed in Chapter 1. To include past values, time series techniques have been found to provide an appropriate methodology in many areas, also discussed in Chapter 1. In this context Brinkworth [1977] found that the sequential characteristics of daily total solar radiation data in the UK could be well represented with a simple first-order autocorrelation model. Goh and Tan [1977] used a first-order autoregressive model for hourly/daily totals of solar radiation recorded in Singapore, and Amato et al [1985] described daily global solar radiation sequences in Italy as a first-order autoregressive process.

In this study more sophisticated time series models, Seasonal Autoregressive Integrated Moving Average models, were fitted to the horizontal and vertical solar irradiance data.

When modelling the averaged winter data detailed in Table 2.2.1 it was important to include a seasonal autoregressive parameter at lag k, to take into account the solar irradiance recorded at the same time on the previous day. For untransformed and transformed solar irradiance data, models of the form

$$\text{ARIMA}(p,d,0)(P,0,0)k \quad \text{with } p = 1,2,3,4 \text{ and } d, P = 0 \text{ or } 1, \qquad \text{Eq. 6.4.1}$$

were fitted where k is the daily cycle length. For 10 minute averages two autoregressive parameters were required but this was reduced to one for 20, 30 and 60 minute averaged data, since the significance of the lag 1 autocorrelation coefficients was reduced and the lag k autocorrelation coefficient increased.

ARIMA models for 10 and 20 minute averaged summer data, on the other hand, depend more on successive values. Modelling indicated that the seasonal component could be omitted and models of the form

$$\text{ARIMA}(p,d,0) \quad \text{with } p = 1,2,3,4 \text{ and } d = 0 \text{ or } 1, \qquad \text{Eq. 6.4.2}$$

were fitted to the averaged summer data.

However, with the increased sampling interval, 30 and 60 minute averaged data, the lag k coefficient is more significant and resulted in fitting models of the Eq. 6.4.1. This is due to the greater number of observations per day available in the summer months, which in turn reduces the influence of the lag k coefficient for shorter sampling intervals. Again the models fitted to the 10 minute data were generally better than the models fitted to 20, 30 and 60 minute data, whether horizontal or vertical for both original and log transformed. From Table 6.4.2, models fitted to horizontal summer data averaged about a 10% lower %R^2 value than the same models fitted to vertical summer data.

It is evident that an ARIMA(1,0,0)(1,0,0)k model is appropriate for 20, 30 and 60 minute averaged winter data and 30 and 60 minute averaged summer data. However, this type of model is not appropriate for 10 minute averaged winter data which requires an ARIMA(2,1,0)(1,0,0)k model to adequately describe the recorded solar irradiance data. While 10 and 20 minute averaged summer data requires an ARIMA(p,1,0) model, where p = 2 or 4. A sampling interval less than or equal to 30 minute averages result in good ARIMA models for log transformed winter data while a sampling interval of less than 20 minute averages give good ARIMA models for log transformed summer.

Values of %R^2 obtained for averaged winter data are displayed in Table 6.4.1. From this table models fitted to the 10 minute data were generally better than the models fitted to 20, 30 and 60 minute data, whether horizontal or vertical. Models fitted to original data resulted in lower %R^2 values but the characteristic decrease in %R^2 value as the sampling interval increased was still evident.

For summer data models fitted to original data resulted in lower %R^2 values but the same characteristic decrease in the %R^2 value occurred as the sampling interval increased. Comparing these values with those obtained for winter data, it is noticeable that summer data returns a higher %R^2 value than winter data. This could be due to there being more observations available in summer months or summer weather being more consistent, and so provide for better models. Analysing the log transformed data does not alter the type of model most appropriate for the data but in a majority of cases the %R^2 value is improved significantly, by up to 12%, irrespective of season or sampling interval. Modelling first-differenced data, that is the change in solar irradiance from one time point to the next, resulted in no significant improvement over original data. These results illustrate the similarities between horizontal and vertical irradiance which was evident throughout, also the dramatic drop in the effectiveness of models fitted to 60 minute averaged data.

Table 6.4.1 Range of $\%R^2$ values obtained for 10, 20, 30 and 60 minute averaged Horizontal and Vertical Winter data

$\%R^2$	10	20	30	60
Horizontal	78-86	64-76	56-70	42-47
Vertical	77-83	69-74	52-67	36-44

Range of $\%R^2$ values obtained for 10, 20, 30 and 60 minute averaged Log Transformed Horizontal and Vertical Winter data

$\%R^2$	10	20	30	60
Horizontal	81-88	70-79	64-71	40-56
Vertical	80-87	69-76	56-65	36-49

Table 6.4.2 Range of $\%R^2$ values obtained for 10, 20, 30 and 60 minute averaged Horizontal and Vertical Summer data

$\%R^2$	10	20	30	60
Horizontal	66-79	60-76	62-75	57-70
Vertical	72-84	67-81	68-80	56-76

Range of $\%R^2$ values obtained for 10, 20, 30 and 60 minute averaged Log Transformed Horizontal and Vertical Summer data

$\%R^2$	10	20	30	60
Horizontal	76-85	60-79	65-77	55-64
Vertical	84-91	75-86	74-84	65-74

Also for one record I subtracted the theoretical solar irradiance for that day and calculated the spectral of the residuals. The periodogram and the spectral density function of the residuals contained all the same charatcteristics as the observed data and therefore did not improve on the information already contained in the autocorrelation functions. Figure 6.4.2 displays a plot of the residual plotted against time for the data recorded on 17/7/94. Figure 6.4.3 and Figure 6.4.4 display the Spectral analysis of the residuals, from these graphs it is apparent that the residuals contain no more information that the observed data.

Figure 6.4.1 Theoretical and Observed Solar Irradiance on a Horizontal surface

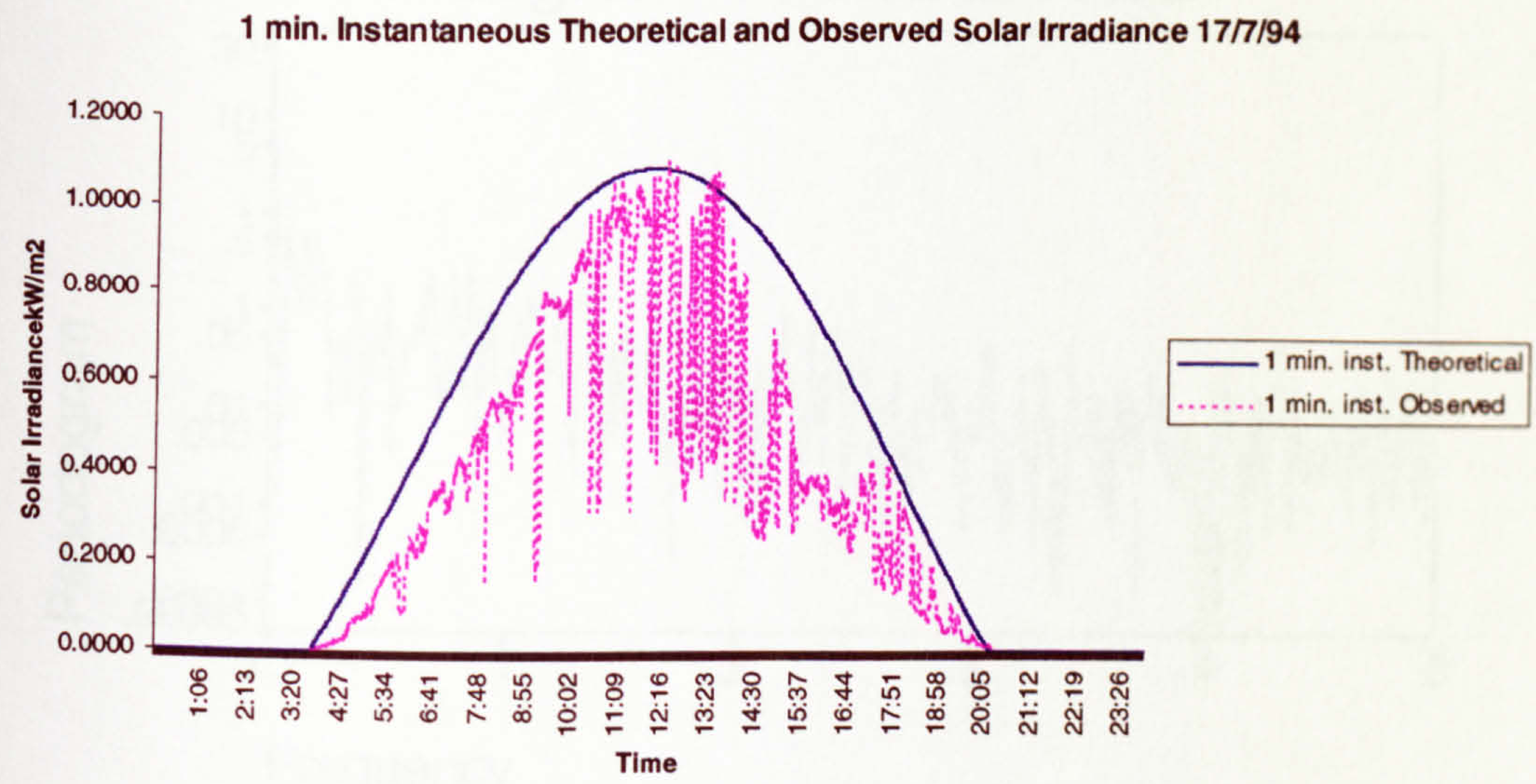


Figure 6.4.2 Theoretical minus Observed Solar Irradiance on a Horizontal surface

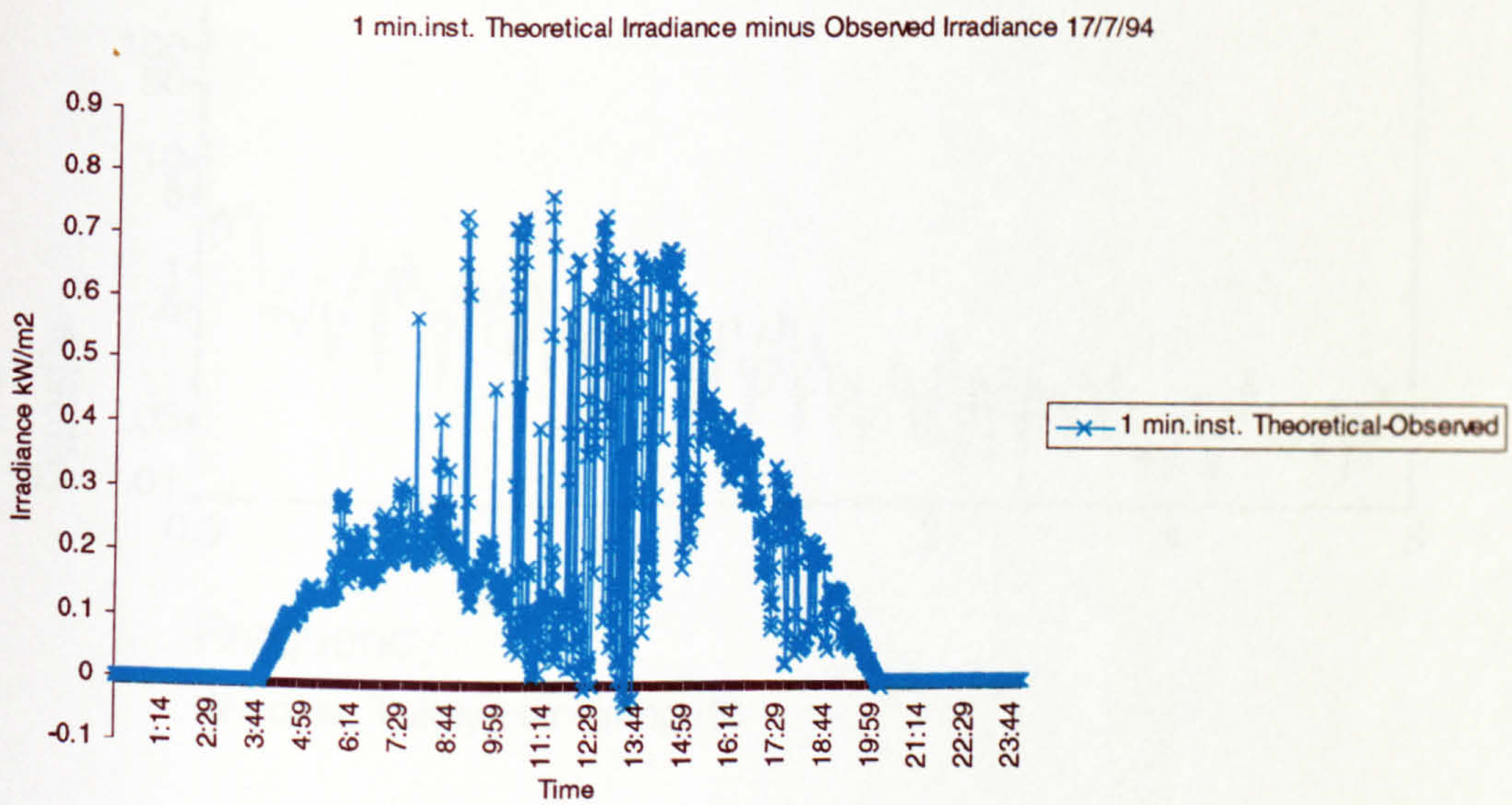
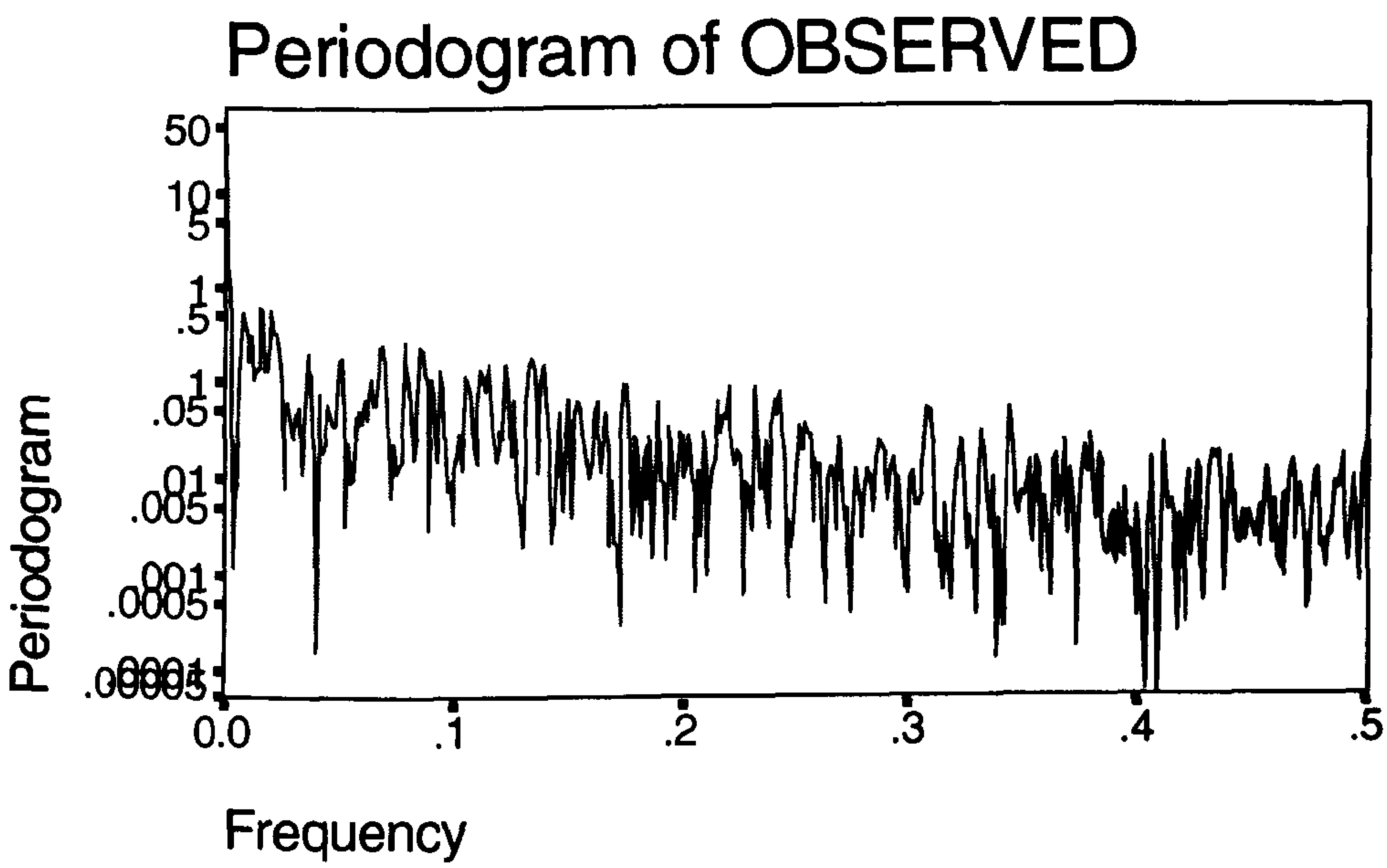


Figure 6.4.3 Periodogram and Spectral Density of Observed Solar Irradiance 17/7/94



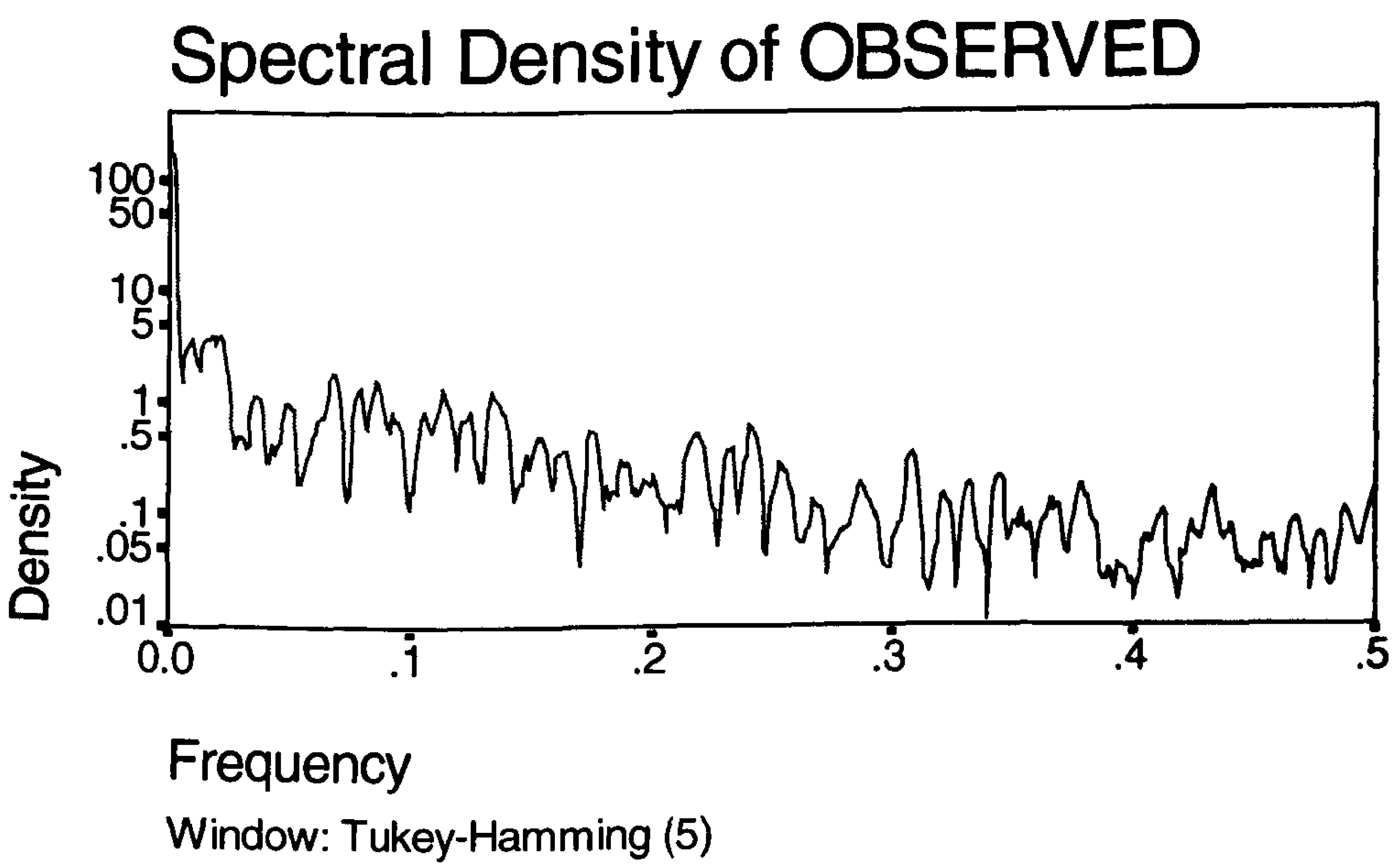
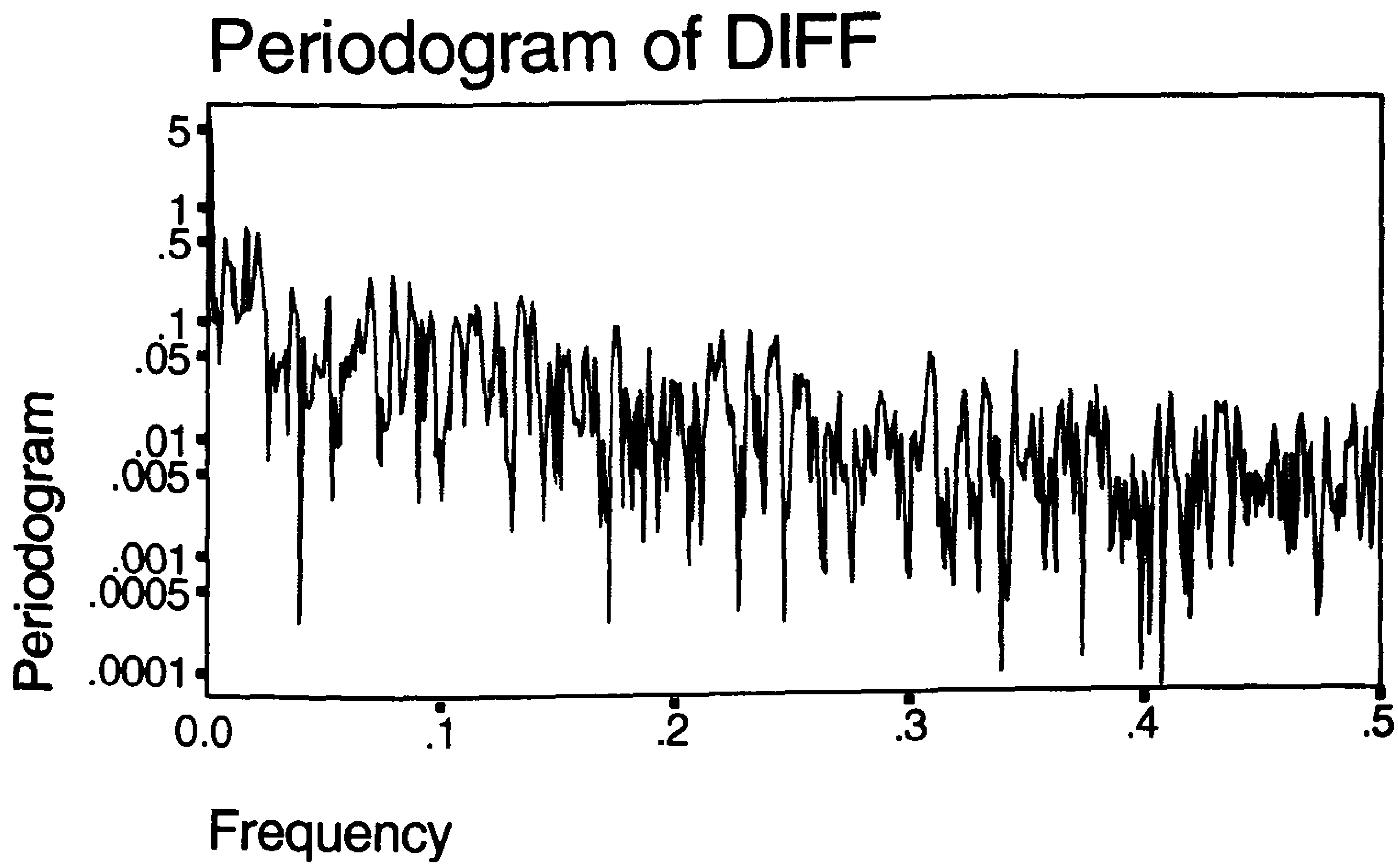
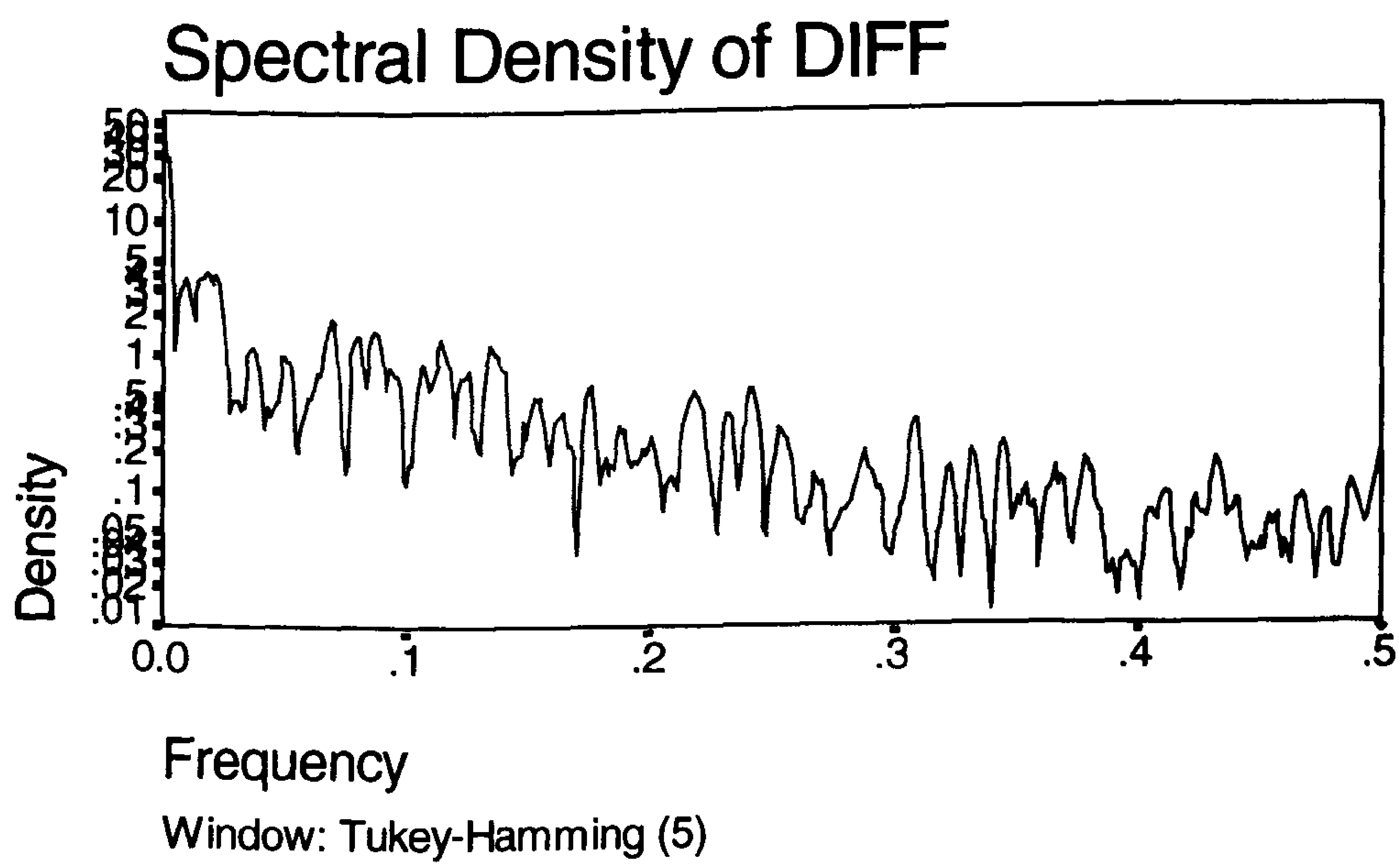


Figure 6.4.4 Periodogram and Spectral Density of Residuals Solar Irradiance 17/7/94





6.5. Modelling Shorter Sampling Intervals for Instantaneous and Averaged Data

Delaunay et al [1994] while investigating the influence of the sampling interval in measurements of direct, global and diffuse components of solar irradiance found that in the case of rapidly changing cloud cover the use of a long sampling interval (15 minute averages) for determining the averaged irradiance over a short time (1 day) will increase the dispersion of the measured data. They also concluded that the occurrence of such weather conditions, i.e. rapid cloud change, depends on the local climate at the measurement site. This paper and the paper by Suehrcke and M^c Cormick [1988] emphasise the need for sustained monitoring of solar irradiance at a particular site with models to be derived from that particular data rather than assumptions made from models obtained from other sites. Ookouchi and Nawata [1991] proposed a simple model for forecasting diurnal weather change in the summer season using past data of that day. One-minute averaged data was recorded for a period of summer days which was then equally divided into 'fine', 'bad' and 'middle' type days according to the number of hours of bright sunshine were recorded on that day. Data recorded up until 10am Japan Standard Time was used to forecast daily weather conditions for the entire day. In an attempt to apply a variation of this method to Newcastle, 1 minute solar irradiance data recorded in July 1994 and December 1995 was divided into 'good', 'variable' and 'overcast' type days, according to the percentage sunshine for that day, and each day modelled separately.

The most appropriate ARIMA models were of the form ARIMA(p,1,0) with p= 1, 2, 3 or 4. For the July 1994 and December 1995 solar irradiance it is clear that as the sampling interval is increased the required number of AR parameters decreases (see Table 6.5.2). For example when modelling 1 minute instantaneous data, 2 or more AR parameters are required to model the data adequately while only 1 AR parameter is required to model 10 minute instantaneous data. The averaged data also requires less AR parameters as the sampling interval is increased.

There were differences between the types of day. With the data divided into 'good', 'variable' and 'overcast' type days, it is noticeable from Table 6.5.1 that the $\%R^2$ value decreases with increased sampling interval, and that the log transformed data returned higher $\%R^2$ values. It is also noticeable that 'variable' type days return a lower $\%R^2$ value than 'good' or 'overcast' days. This is due to the high variance on such days. Hence log transformation stabilises variance which increases with the mean rather than variance per se.

It is also noticeable that 5 and 10 minute averaged July 1994 data requires an extra AR parameter for 'variable' type days and not for 'good' or 'overcast' type days. For December 1995 'variable' type days at the shorter instantaneous sampling intervals require more AR parameters than 'overcast' type days, while averaged data for 'good' and 'overcast' type days require only one AR parameter.

There were also observable differences between models fitted to horizontal and vertical winter and summer solar irradiance data. Models fitted to July 1994 vertical data on average returned a higher $\%R^2$ value than horizontal data, while for December 1995 the horizontal models returned a greater $\%R^2$ value than vertical data. There are days in both July 1994 and December 1995 for which an ARIMA model could not be determined, particularly 5 and 10 minute instantaneous data for July and 1, 5 and 10 minute instantaneous data for December. This was because the estimation did not converge to the specified criterion in Minitab and no model was found[7].

In general the $\%R^2$ decreased as the sampling interval was increased, as was to be expected as the correlation of consecutive terms is reduced. For example, the mean $\%R^2$ value for models fitted to vertical data recorded in July 1994 decreased from 91% to 78% to 68%, for 1, 5 and 10 minute instantaneous data, respectively (see Table 6.5.3). This characteristic decrease in the $\%R^2$ value as the sampling interval was increased was also evident for models fitted to horizontal July 1994 data and horizontal and vertical December 1995 data. Again, the log transform was found to improve the $\%R^2$ values obtained, for example models fitted to 1 minute instantaneous December 1995 horizontal data had a mean $\%R^2$ of 88% while models fitted to the log transformed horizontal data had a mean $\%R^2$ of 95%.

It is also noticeable that the mean $\%R^2$ value obtained from models fitted to 5 minute averaged data were greater than those obtained from models fitted to 5 minute instantaneous data. Similarly the mean $\%R^2$ value obtained from models fitted to 10 minute averaged data were greater than those obtained from models fitted to 10 minute instantaneous and 5 minute instantaneous data, but neither could improve on the $\%R^2$ obtained by models fitted to 1 minute instantaneous data.

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[7] I could have tried differencing the time series data in C1 and lagging the data in C1 by 1 and placing the result in C2 and then regress C1 on C2. However, I was interested in a semi-automated procedure that could be used with the very large number of time series that were being generated.

Table 6.5.1 Average %R^2 values by type of day obtained for July 1994 and December 1995

July 1994	Type of Day	Horiz	Log Horiz	Vert	Log Vert
	Good	86	97	89	98
1 min. inst.	Average	88	98	89	98
	Overcast	93	97	94	99
	Good	75	93	80	96
5 min. inst.	Average	73	93	76	95
	Overcast	78	98	80	95
	Good	70	89	75	94
10 min. inst.	Average	66	90	69	92
	Overcast	59	96	61	97
	Good	87	96	91	98
5 min. ave.	Average	85	96	86	97
	Overcast	86	95	87	96
	Good	88	96	91	97
10 min. ave.	Average	83	93	84	94
	Overcast	78	90	79	92

December 1995	Type of Day	Horiz	Log Horiz	Vert	Log Vert
	Good	98	98	98	99
1 min. inst.	Average	67	86	47	82
	Overcast	94	98	82	95
	Good	67	69	88	89
5 min. inst.	Average	31	54	19	49
	Overcast	72	77	62	71
	Good	37	47	68	86
10 min. inst.	Average	20	42	?	36
	Overcast	50	57	51	61
	Good	75	75	95	95
5 min. ave.	Average	61	70	40	68
	Overcast	83	85	68	81
	Good	55	54	86	89
10 min. ave.	Average	56	62	36	43
	Overcast	71	70	61	67

Table 6.5.2 Number of AR parameters required to adequately model solar irradiance data, a) July 1994, b) December 1995

a)

ARIMA(p,1,0)	Good Days	Average Days	Overcast Days
1 min. inst.	not enough data	p = 2	p = 2
5 min. inst.	not enough data	p = 1	p = 1
10 min. inst.	not enough data	p = 1	p = 1
5 min. averaged	not enough data	p = 2	p = 2
10 min. averaged	not enough data	p = 2	p = 1

b)

ARIMA(p,1,0)	Good Days	Average Days	Overcast Days
1 min. inst.	not enough data	p = 4	p = 2
5 min. inst.	not enough data	p = 2	p = 1
10 min. inst.	not enough data	p = 1	p = 1
5 min. averaged	not enough data	p = 1	p = 1
10 min. averaged	not enough data	p = 1	p = 1

Table 6.5.3 Overall Average $\%R^2$ values for July1994 and December 1995

July 1994	Horiz	Log	Vert	Log Vert
1 min. inst.	89	87	91	98
5 min. inst.	75	93	78	95
10 min. inst.	64	91	68	93
5 min. ave.	85	95	87	97
10 min. ave.	82	93	83	94
December 1995				
1 min. inst.	88	95	76	93
5 min. inst.	63	73	53	67
10 min. inst.	48	58	54	58
5 min. ave.	80	83	66	80
10 min. ave.	70	71	59	66

6.6. Conclusions

As expected the noise present in the data is reduced as the sampling interval is increased. When considering the 10, 20, 30 and 60 minute averaged solar irradiance data the lag 1 autocorrelation coefficient decreases as the sampling interval is increased which quantifies the serial dependence within the series. The autocorrelation coefficients obtained for summer data are predominately larger than those obtained for winter data. The daily cycle was clearly present in the data with the lag k coefficient more influential within winter data, where it was significant at all sampling intervals, whereas in summer data it was only significant within 60 minute averaged data. This difference between seasons could be due to climatic differences. This characteristic was further emphasised when fitting ARIMA models to the data. Winter data required models of the form ARIMA(p,d,q)(P,0,0)k whereas summer data required models of the form ARIMA(p,d,0). The $\%R^2$ value for fitted models also decreased as the sampling interval was increased in a manner similar to the lag 1 autocorrelation coefficient. There was a considerable reduction in the $\%R^2$ value obtained from models fitted to 60 minute averaged data across both seasons in comparison with shorter sampling intervals, further emphasising that hourly averages are not appropriate for short-term prediction.

The 1, 5 and 10 minute instantaneous and 5 and 10 minute averaged solar irradiance data were analysed and modelled separately. The same characteristics, such as the decrease in the lag 1 autocorrelation coefficient and $\%R^2$ value as the sampling interval increased was evident.

Comparison of the 5 and 10 minute instantaneous data with 5 and 10 minute averaged data showed that the lag 1 autocorrelation coefficient for 5 and 10 minute averaged data was greater than the corresponding 5 and 10 minute instantaneous data. This implies that if 1 minute instantaneous data is considered to be 'complete sampling', i.e. contains all the characteristics of the past behaviour of solar irradiance, and 5 and 10 minute data is 'incomplete sampling', then, since the 5 and 10 minute averaged data has a larger autocorrelation coefficient than the corresponding 5 and 10 minute instantaneous data, averaged data retains more of the past characteristics than instantaneous data.

This work emphasises that hourly averages are not appropriate for short term predictive purposes (at latitudes greater than 40^0 N or 40^0 S). It also highlights that averaged data retains more of the past characteristics of solar irradiance than instantaneous values. From this study, based in Newcastle-upon-Tyne, the best sampling interval was concluded to be 10 minute averaged data for winter months and 10 or 20 minute averaged data for summer months. The end user has to decide which $\%R^2$ value best satisfies their particular situation, how much information-loss they are prepared to accept and how much data they want to record. A further reason why the researcher preferred averaged data over instantaneous data was that the amount of data produced by sampling at say 1 minute intervals, especially in the summer months, was enormous and lead to problems when fitting models with the computer software used. This is an important practical consideration, but software will have improved in the interim and this will need to be reviewed.

There were distinct differences in levels for horizontal and vertical solar irradiance but they are highly correlated and have very similar results. However, little work has been carried out in modelling both horizontal and vertical solar irradiance for the same location. There has also been no previous systematic study of sampling intervals with regard to recording solar irradiance for modelling purposes. Modelling and forecasting solar irradiance at shorter sampling intervals within an urban environment would help the development of fully integrated large-scale Photovoltaic Systems which would provide a stand-by power source for the National / Local Grid at times of peak demand.

This study however shows that the sampling interval to be an important consideration, but ultimately depends on the nature and scope of the intended research.

6.7. Recommendations

Investigation of 10, 20, 30 and 60 minute averaged data clearly indicated that hourly averages were not appropriate for modelling the short-term fluctuations in solar irradiance at this site. Although this was an urban site in the northern latitudes where weather conditions can change very rapidly, it was thought that similar conclusions would be reached at other urban sites in the northern latitudes. However, it is not enough to model data recorded at one urban site, i.e. Newcastle-upon-Tyne, UK. This should be extended to other urban sites around the UK, Europe and other parts of the world. As already mentioned, for solar energy to compete against other well-established forms of energy it has to become accessible to urban centres. To do this, more urban environments need to be studied initially on a separate basis and then as a network of such sites around the UK.

From this investigation, 10 minute averaged data provided the best models for 13-15 day periods for both horizontal and vertical solar irradiance data for both summer and winter months. This work should be extended to cover all months of the year, not just summer and winter months, modelling 10 minute averaged data for 15-day periods and monthly (30/31-day) periods, to produce ARIMA models for each period/month for consecutive years so that models can be compared, and yearly trends analysed in more detail to extract best parameter values month by month. This could then be used to establish a database of 20-30 years of such models to be compared year by year and month by month.

In the analysis of the shorter sampling intervals, a problem arose from the number of 1 minute observations recorded. The statistical software package used could not handle 13-15 days of 1 minute instantaneous data. Hence these data were analysed on a daily basis. However, I would anticipate that future technology will be more able to cope with the large volumes of data generated with recording data at 1 minute intervals. Despite this, good models were obtained (%R^2 greater than 90%) using ARIMA models. The 5 and 10 minute instantaneous and averaged data for these periods were also analysed on a daily basis so that a direct comparison could be made. It became clear in the analysis that increasing the sampling interval decreased the % goodness of fit but this decrease could be reduced if averaged data rather than instantaneous data was modelled.

An attempt was made to divide the sampling period into three groups, 'good days', 'variable days' and 'overcast days' following a similar methodology employed by Ookouchi and Nawata [1991]. However there were only two 'good days' in the June 1994 dataset and none in the December 1995 dataset. This analysis could be extended to cover a larger sampling period to include a larger number of 'like classified' days. This method of modelling solar irradiance on a daily basis and classifying the days as 'good', 'average' and 'overcast' should also be used on the initial 10 minute averaged data mentioned above.

A more detailed analysis of prevailing weather fronts is also required. Cloud movement is an important factor in solar irradiance but, from the Meteorological data available for Newcastle-upon-Tyne, cloud cover is measured by eye and only for 6-12 hour periods. A more quantitative measurement is needed at shorter sampling intervals to coincide with recorded solar irradiance data to allow the possible incorporation of this information into any future solar irradiance model.

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